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EVALUATION OF REMOTE SENSING TECHNOLOGY FOR MONITORING CHRONIC OIL DISCHARGES FROM OFFSHORE WELL SITES

EE-68

EVALUATION OF REMOTE SENSING TECHNOLOGY FOR MONITORING CHRONIC OIL DISCHARGES FROM OFFSHORE WELL SITES

by

Martec Limited
Halifax, Nova Scotia

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PART 1

INTRODUCTION

1.0 INTRODUCTION

1.1 GENERAL

Within the last 15 years, significant hydrocarbon discoveries have been made in Canadian offshore waters on the Scotian Shelf, the Grand Banks, in the Beaufort Sea, and the Canadian Arctic Islands. Exploration is continuing in all these areas and delineation drilling to determine the extent of discoveries is proceeding. If commercial reserves are proven and economic conditions are favourable, gas and oil production from these areas could begin in the late 1980's or early 1990's.

Associated with this activity is the risk of loss of hydrocarbons into the marine environment, arising from accidents or from chronic low volume discharges associated with routine production activities. Losses associated with well blowouts and tanker accidents are more easily observed and generally well documented. Conversely, small discharges of a chronic nature can go undetected and unreported.

Chronic low volume discharges could originate from four main sources:

- production water;
- ballast water;
- operational discharges, and
- disposal of oil-based drilling muds.

Production water is formation or reinjected water produced from a well during the course of recovering hydrocarbons. Production water which is not reinjected into the well is usually treated to remove hydrocarbons using oil-water separators and is then discharged into the ocean. The second potential source is ballast water. Analogous to ship's ballast, some offshore installations use seawater to ballast floating oil storage systems and to displace oil from storage into tankers. As with production water, displaced water is usually passed through a separator and discharged

overboard, but some residual hydrocarbons may remain in the effluent.

Operational losses can include lubrication oils and fuels as a result of leaks, slops and spillage on the facilities themselves, as well as spillage during fuel transfer operations. Although most of these are contained and treated by the on-board oil-water separation system, some of these losses could enter the environment. The final source is low toxicity oil-based drilling muds which have recently been introduced to offshore drilling operations on the east coast. Cuttings are treated to remove most of the oil, but small quantities of the drilling mud adsorb to the cuttings and are discharged overboard.

These discharges are, for the most part, small, but human error or mechanical failures in the collection or treatment systems could result in measureable losses into the marine environment. A requirement to monitor the presence of hydrocarbons arising from these sources is the basis for this study.

Research and technological advancements in the last few years have resulted in the development of passive and active remote sensing systems with potential for detecting oil on the water surface or in the near surface layers of the water column. One or more of these systems could be integrated into an automated remote sensing package mounted on a vessel or an offshore platform. However, the oil detection capabilities and operational performance of these systems must be properly assessed before they can be used on a continual basis for detection of hydrocarbon releases.

1.2 PROGRAM OBJECTIVES

This program is the second in a series of investigations to assess the ability of existing remote sensing packages to perform the monitoring task described above. The first study (Bercha, 1984) entailed a literature search to identify current remote sensing technology which might be applicable for detecting oil in the offshore environment.

The present study involved field testing of a suite of sensors at Dartmouth, Nova Scotia in February 1985. The objective was to determine the detection capabilities and operational performance of the sensors under a variety of environmental conditions.

The sensors included an Infrared (IR) imager, a Pyro-Electric Vidicon, a vapour detection unit, a low light level television camera (LLLTV) and two photographic cameras. The system was operated for approximately two weeks and spanned all available lighting and environmental conditions. This report describes the organization and execution of the field program and the results obtained.

1.3 REPORT FORMAT

This report is presented in five parts. Part 1 introduces the project and identifies the scope and objectives of the program. Part 2 contains a brief technical summary of the units tested during the field program. Part 3 describes the design and execution of the field program. The results and a comparison of the capabilities of each sensor are presented in Part 4. Part 5 contains a summary of the findings and recommendations for future investigation. Supporting technical information, data, videotapes, and photographs are available from the Scientific Authority.

PART 2

TECHNICAL SUMMARY OF SENSORS

2.0 TECHNICAL SUMMARY OF SENSORS

This part of the document includes a brief technical summary of the sensors tested during the field evaluation program. A short section describing the theory behind the use of remote sensing devices to detect oil on water is presented as a preamble to identification of the sensors themselves.

2.1 DETECTION OF OIL ON WATER

Detection of oil on a water surface or in near surface layers depends on the ability of a sensor to determine a contrast between the oil and the background. An increase in contrast improves the ability of a sensor to detect the presence of oil. Contrast can be due to differences in the reflectivity, emissivity, transmissivity, luminescence, fluorescence, and form or shape of the two media. The contrast may be enhanced by the choice of an appropriate waveband, polarization, the period of observation, and the sensor orientation to both the sun and water surface. Contrast can be diminished by atmospheric attenuation and local conditions such as cloud cover, humidity, waves and water turbidity.

Remote sensing is restricted to the bands of the electromagnetic spectrum in which atmospheric transmittance is high. The most commonly used window is the band from 0.3 μm to 2.0 μm which includes the visible and part of both the ultraviolet (UV) and the near infrared (NIR) regions, but others used include the mid-infrared (3.0 to 5.0 μm) and the thermal or far infrared band, with wavelengths from 8.0 to 14.0 μm. Operation in other regions, such as the microwave, is possible but this is not considered in this report.

During daylight hours, the spectral content of sunlight and back scattered radiation influence the ability of the passive sensors to detect oil. A clear sky has a high blue content. This condition favours detectors operating in the blue and UV regions. Water vapour in the

atmosphere results in a flatter spectrum with a relatively larger red component which favours sensors optimized more towards the red region of the spectrum.

At night, sensors using the UV or visible part of the spectrum will be essentially inoperable unless image intensifiers are used. However, thermal IR sensors can still function effectively if local conditions are favourable.

The detection of oil on water by remote sensing units operating in the different regions of the spectrum is described below.

2.1.1 Ultraviolet and Visible

Oil is seen on the water surface since it has a greater index of refraction and therefore appears brighter than the water. It has been calculated that the surface reflectance of representative crude oil as compared with that of water is greater by a factor of 2.1 at a wavelength of 0.4 μm and 1.6 at a wavelength of 1.2 μm. There are, however, two factors that tend to mask the presence of oil and reduce the oil-water contrast. These are a volume reflection component, as a result of back-scatter from within the volume of the water itself, and a path radiance component from the intervening atmosphere between the surface and the sensor.

The most consistent results are therefore obtained by measuring the radiation reflected from the surfaces while minimizing the detection of the volume reflected and path radiance components. A number of techniques can be used, but the most common involve polarization of the radiation at the sensor and the selection of an appropriate segment of the spectrum to measure.

By directing a sensor at Brewster's angle, which is approximately 53°

from the vertical for sea water, the surface reflected radiation from a flat water surface is 100% perpendicularly polarized, i.e., the radiation is polarized perpendicular to the plane of incidence and hence imparts a horizontal component. The presence of waves will reduce the polarization, but it will not usually be less than 92% (O'Neil et al., 1983). For angles differing from 53°, the degree of polarization drops off to 80% at 65° and 41° under calm water conditions. At the same time, when viewing a surface at Brewster's angle away from the sun, and with a sun altitude of between 20° and 70°, the water volume reflected radiation is polarized in the orthagonal direction which imparts a vertical component. The degree of polarization, however, cannot be expected to exceed 12%. Likewise, the path radiance is also horizontally polarized, but usually less than 10%.

Thus, viewing at or near Brewster's angle and receiving the radiation through a polarizer set to transmit the horizontal component will eliminate less than 5% of the surface reflected radiation while blocking up to 56% of the water volume reflected radiation and at least 45% of the path radiance.

Selection of an appropriate spectral range will also enhance the oil-water contrast. Both the reflectivity and absorptivity of oil are higher in the near UV region of the spectrum (Horvath et al., 1970; Rayner, 1979). As stated earlier, the reflectivity of oil is higher than that of water by a factor of 2.1 at a wavelength of 0.4 μm. As well, the absorptivity of the oil in this band will cause absorption of radiation emerging from the water volume. This will tend to decrease the volume component received at the sensor except in circumstances such as highly emulsified oil where the many scattering centres will make the oil appear bright. The volume reflected component for water has a maximum radiance at 0.45 to 0.65 μm (Neville et al., 1979) so that filtering for the near UV will further minimize the volume reflected component.

In using UV or visible bands of the spectrum, the surface reflected to background ratio of radiation received by the sensor can be increased by

a factor of two by using a horizontally aligned linear polarizer. Further gains can be made if the near UV band of the spectrum is used. Although sensing in the near UV results in a high path radiance when operating at high altitudes, the sensor height for the proposed application will be generally less than 50 m and the quality of the signal should not be severely degraded.

2.1.2 Thermal Infrared

The thermal infrared (TIR) is one of the most useful and yet one of the most complex spectral regions for use in oil detection on water. The contrast in the signal between oil and water depends on the emissivity of the medium, surface temperatures, thermal conductivity, thermal diffusivity, solar heating, and evaporation rates. Generally, oil has a lower emissivity than water and appears cooler to an IR sensor. For example, at 8.5-12.5 μm the emissivity of the water is about 0.988 and that of oil is 0.94-0.97. Thus, the oil will have a radiant temperature lower than that of water. The thickness and type of oil influence the apparent temperature. Oil can appear as much as 3° K lower. In the temperature range 275-295° K a 1% reduction in the emissivity results in a 0.6° K drop in the apparent temperature. If the emissivity of oil is 2-5% less than that of water, then a 1-2.5° K contrast is expected (Buettner, 1965; Munday, 1971). Contrast due to real temperature differences will be highest at mid-afternoon on a clear day and contrast due to the difference in emissivity will be greatest on an overcast day with little wind.

Different temperatures between the media occur for a number of reasons. The primary one is that an oil slick can absorb sufficient solar radiation to heat it above the water surface temperature. Oil near the source of a slick may also retain its initial temperature which could be different from that of water. This will occur for only a short time after discharge. In addition, an oil film can insulate the water surface, resulting in an increased or decreased surface temperature depending on whether the air temperature is above or below the water temperature.

Some form of temperature distribution distinguishing the oil from the water will inevitably occur, since it is unlikely that all the variables will balance, rendering the oil undetectable.

The limiting factor to oil detection and interpretation in the TIR will therefore be the sensitivity of the detector, the experience of the interpreter and the accuracy to which various parameters (such as water and oil temperatures, and emissivities) are known.

2.2 SENSOR PACKAGES

This section identifies the sensors evaluated during the field program, including their theory of operation and technical specifications. The sensors used in the program were:

- two photographic cameras;
- a low light level television system;
- a pyro-electric vidicon;
- a thermal imager; and
- a vapour detection unit.

An infrared oil film monitoring device originally planned for inclusion was unavailable.

All the units tested were passive data acquisition systems.

2.2.1 Photographic Cameras

Two photographic cameras were used in the program. The primary camera was a 2 1/4" by 2 1/4" Hasselblad 500 EL/M fitted with a Zeiss CF 105mm lens. This is a specialized lens constructed of quartz and fluorite which has the ability to transmit ultraviolet radiation. Since oil slicks are highly reflective in the near UV, limiting the spectral range of a sensor to these wavelengths will enhance the oil-water contrast. A Wratten 18A

filter which transmits radiation in the waveband 0.335 to 0.395 μm was mounted in front of the camera lens to achieve this goal. During the evaluation, the film used in the camera was Kodak Tri-X black and white print film.

A regular 35 mm camera without specialized lenses and filters was used for comparative purposes. Both black and white and colour film were used in this unit.

The specifications for the photographic cameras were as follows:

Camera	Hasselblad 500 EL/M	Pentax ME-Super
Lens	Zeiss CF 105 mm f/4.3	Pentax 50 mm f/1.2
Film	Kodak Tri-X B&W	Kodacolor 200 and Ilford XP1.
Film Capacity	20 exposures	36 exposures
Filter	Wratten 18A (filter factor 8-20X)	None

2.2.2 LLLTV

Low light level television (LLLTV) cameras employ image intensifiers to enhance sceen illumination. They are capable of providing images at very low light levels, but not in total darkness.

The LLLTV used in this program was a RCA Model TC1030H fitted with a Corning 7-51 filter and a linear polarizer. The Corning 7-51 filter limits the spectral range of the camera to the near UV where the oil-water contrast is greatest. To further enhance the contrast between the surface reflected components, a horizontal polarizer was also used. As indicated in Section 2.1.1, light reflected from the water surface is polarized differently from that reflected from within the water volume or by the atmosphere. A horizontally aligned polarizer will pass the surface reflected component while minimizing the volume reflected components. Specifications for the LLLTV camera and filters are given in Table 2.1 while the spectral sensitivity of the LLLTV is shown in Figure 2.1.

TABLE 2.1

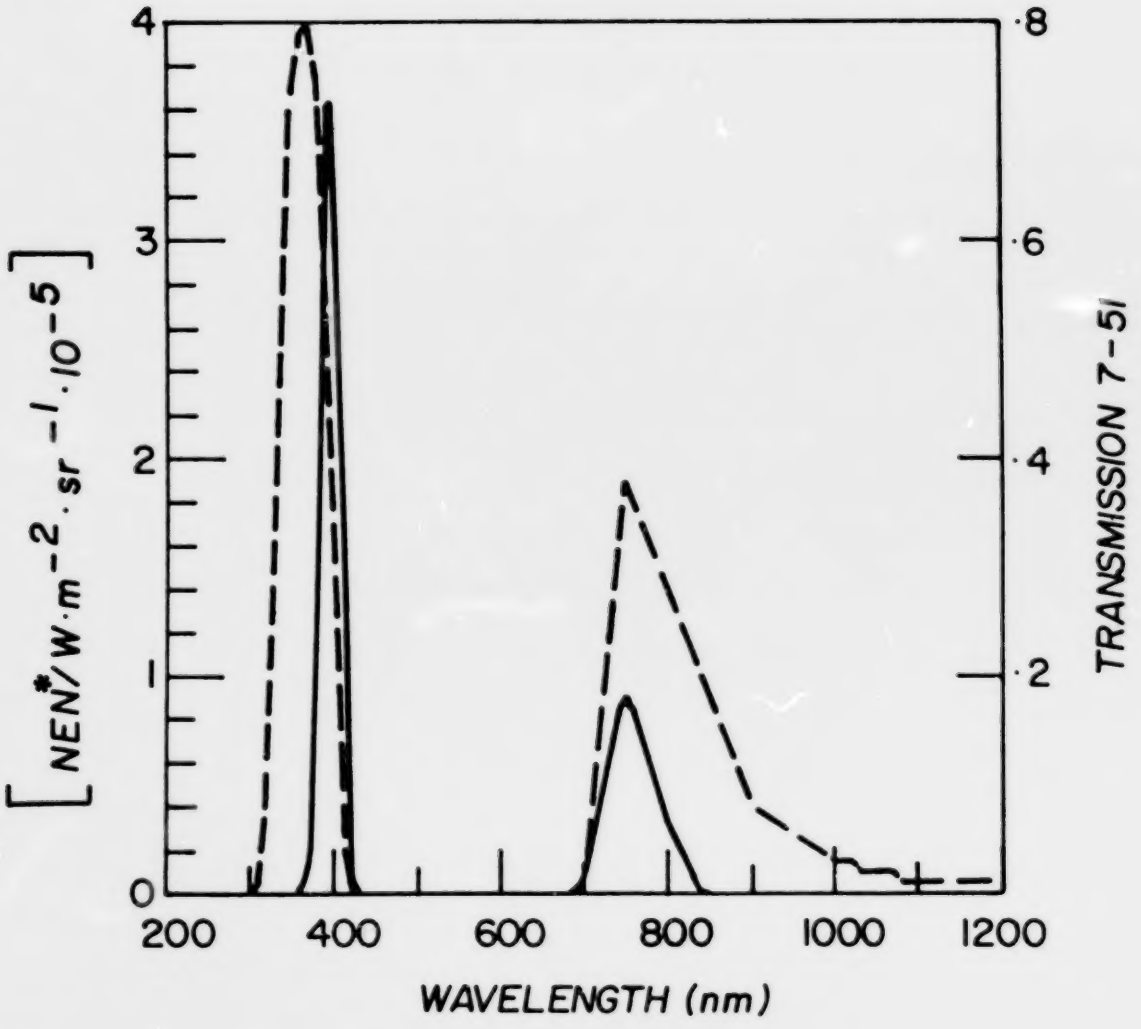
SPECIFICATIONS OF THE LLLTV AND FILTERS

Camera - RCA TC1030H

Description:	A low bloom, high contrast, medium resolution, Silicon Intensified Target television camera.
Lens:	Fujinon TV LH15A2 f/1.4, 12.5 mm focal length, 42.4° x 54.4° field of view.
Spectral response:	380-850 nm, full width.
Light range:	10^{8}
NEN:	$10^{-9}Wm^{-2}\cdot sr^{-1}$; $5x10^{-12}Wm^{-2}\cdot sr^{-1}\cdot nm^{-1}$
NEN as outfitted with polarizer and UV filter	$1.1x10^{-7}Wm^{-2}\cdot sr^{-1}$(370-420 nm, full width) $1.5x10^{-7}Wm^{-2}\cdot sr^{-1}$(690-840 nm, full width)

Filters

	Polarizer	UV Filter
Type	Polaroid HNPB	Corning 7-51
Transmission	240-740 nm	310-320 nm and 700-1,100 nm
Filter Factor	2.8 x	8-20 x



——— SPECTRAL SENSITIVITY OF RCA TC1030H CAMERA

– – – – TRANSMISSION OF CORNING 7-51 FILTER

*NOISE EQUIVALENT RADIANCE

SOURCE: O'NEIL ET AL., 1983

FIGURE 2.1

SENSITIVITY OF RCA TC1030H CAMERA WITH CORNING 7-51 FILTER

2.2.3 Pyro-Electric Vidicon

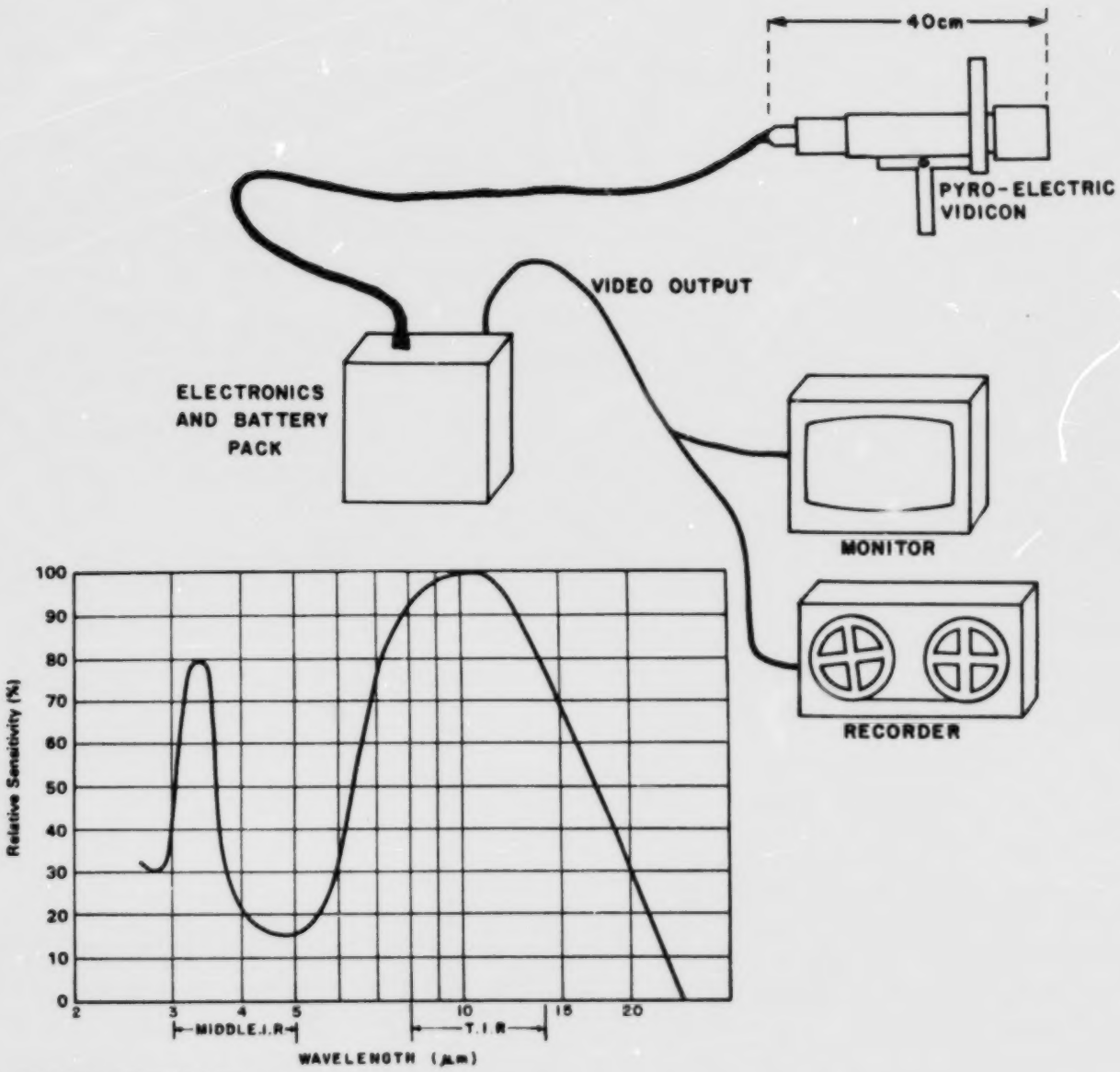
Recent advancements have led to the development of a camera system optimized for operation in the far IR. These sensors differ from IR scanners in that the scanning is done electronically rather than mechanically. This system has few moving parts and does not require a detector cooling system. These features combine to produce a compact, operationally reliable and relatively less costly instrument.

The pyro-electric vidicon tested was the System 8020 manufactured by Thermal Imaging Ltd. in Great Britain. The specifications and a plot of the spectral response are shown in Figure 2.2. It is a portable unit, with a hand-held sensor head, and a portable electronics unit which includes a battery and an electronic viewfinder. It may be used with or without a chopper. The chopper is used when no motion is present in the field of observation. The chopper, however, reduces the sensitivity of the instrument beyond that at which oil can normally be detected. As a result, it was not used during the test program. Operation is optimal in the 8-14 μm band. Other IR Bands are received at a lower efficiency.

2.2.4 Infrared Imager

Remote sensing systems operating in the Thermal Infrared have, in the past, been complicated instruments requiring highly skilled operators and a specialized maintenance staff. As a result of recent technological improvements and declassification by the military, a relatively simple and robust Thermal IR imagery system is now available. The Barr and Stroud IR18 was chosen for this evaluation since it is relatively compact, robust, and provides good resolution. The detector is air cooled which is an advantage over other far IR imaging devices which require liquid nitrogen as the coolant.

The system consists of three main units: a telescope, scan head, and electronics processor as shown in Figure 2.3. Specifications of the system are given in Table 2.2.



TECHNICAL SPECIFICATION:
Standard head 50mm f/0.8, IR transmission 8-14 microns.
Optional heads, 18mm, 25mm, 75mm, 100mm, 130mm.
Detector head, P.E.V. used in panning mode or chopped mode, changed by switch.
Resolution, 220 TV lines @ 1°C temperature difference.
100 TV lines @ 0.25°C temperature difference.
Bandwidth, 5 MHz
Linearity, ± 2%
Line standard, 525 lines @ 60 fps, or 625 lines 50 fps.
Video output, composite into 75 ohms.
Recording, direct to any standard V.C.R.
POWER SUPPLY: Battery pack, 12vdc with built in charger for 115VAC or 240VAC.
Switch provides external power supply feed.

FIGURE 2.2

SPECIFICATIONS FOR THE PYRO-ELECTRIC VIDICON

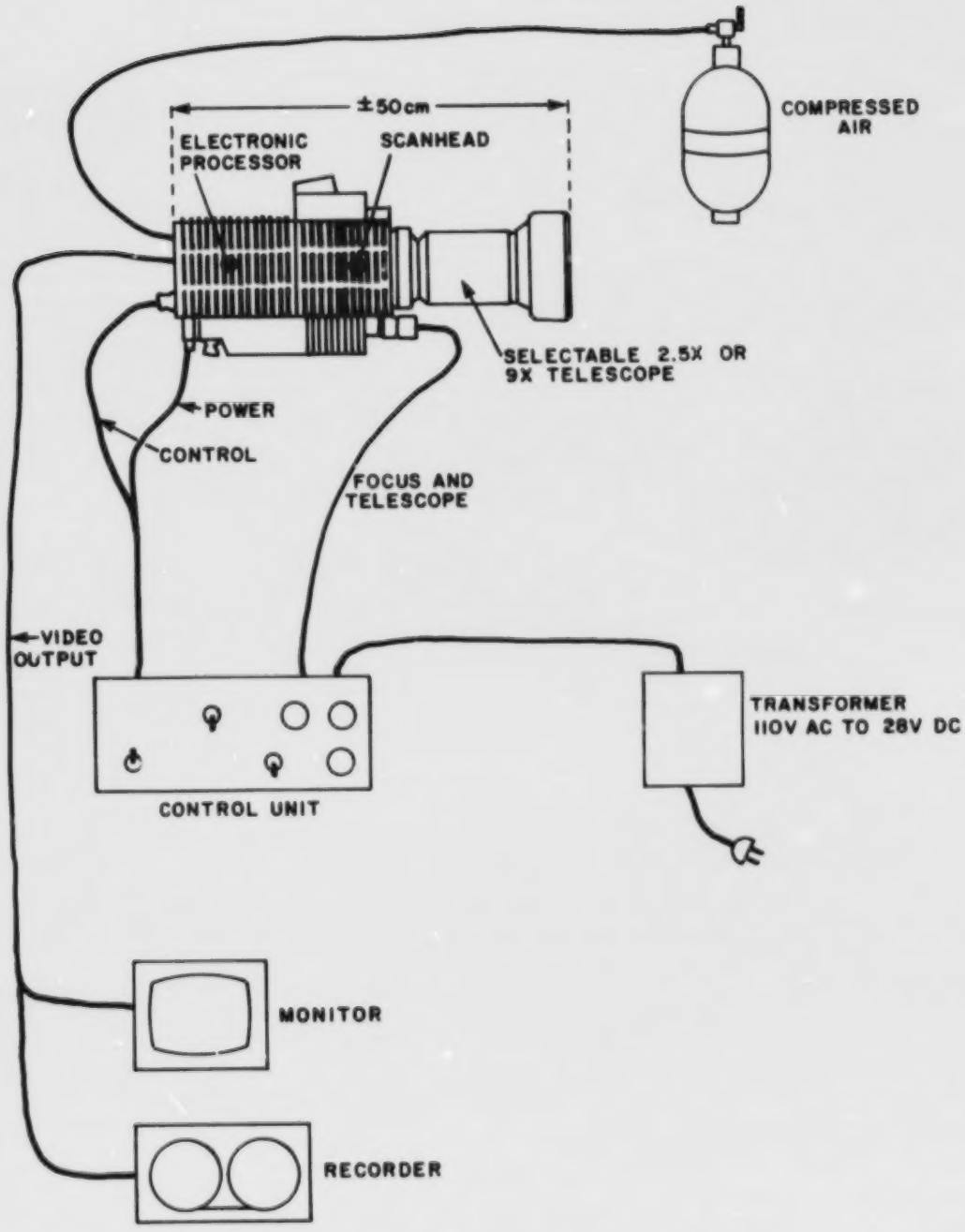


FIGURE 2.3

BARR AND STROUD THERMAL INFRARED IMAGER

TABLE 2.2

SPECIFICATIONS OF INFRARED IMAGER

	Without Telescope	2.5 x	9 x
Horizontal Field of View	38.2°	15.4°	4.2°
Vertical Field of View	25.5°	10.2°	2.8°
Pupil Diameter	14.5 mm		

Maximum Resolution of Temperature (at 0.289 cycles/m radi)	0.17°C - 0.5°C
Detector	Serial/parallel Sprite cooled to 77°K
Spectral bandwith	8.0- 14 μm
Video output	CCIR compatible 1 volt composite video (75 ohm load)
Display	525 TV lines/frame
Field rate	60Hz
Frame rate	30Hz
Cooling Requirement	Clean air to AvP32 standard 1/8in. BSP60° internal cone inlet
Inlet Pressure	4500 psi max at 25°C 1500 psi min
Power supply requirements	24 volts d.c. nominal 20 volts min - 32 volts max
Power consumption	32 watts at 24 volts typical
Weight	
Scan head unit	3.5 Kg
Electronic processor unit	2.2 Kg
Power supply unit	1.1 Kg
Total scanner	6.8 Kg
Controls	Available on scanner rear panel or remote cable operation

TABLE 2.2 (Continued)

SPECIFICATIONS OF INFRARED IMAGER

Power	ON/OFF toggle switch
Sensitivity	5 position gain control providing nominally 2°C, 4°C, 8°C, 16°C, 32°C dynamic range displays
Temperature offset	'Black' level rotary control
Polarity	Two position control providing displayed temperature inversion (Normal - white hot display) (Invert - black hot display)

With this system, infrared radiation is focussed through a telescope and is reflected by an oscillating mirror across a line detector. The electronic processor accepts parallel data from the line detector and converts them to a CCIR compatible video signal. The detector is cooled to 77°K using compressed air and a Joule-Thompson minicooler.

The camera has five main controls: sensitivity, black level, screen polarity, telescope and focus. Sensitivity controls the approximate temperature range displayed at the video output. The five position switch may specify a range of 2,4,8,16 or 32 degrees centigrade. The sensitivity is effectively a contrast control and is adjusted to provide optimum contrast. The imager has a dynamic temperature range of 150°C which is greater than that displayed at any one setting.

The black level adjustment varies the position of the sensitivity within each range selected. The imager also contains a feedback circuit that varies the black level over a range of scene conditions to eliminate the need for continual adjustment.

The screen polarity switch is a two-position switch having a "normal" and "invert" setting. In the "normal" position, hotter objects appear white while cold objects appear black. The "invert" setting reverses the image.

The telescope switch allows magnification to be selected between 2.5 and 9 times. As would be expected, the greater the magnification, the smaller the field of view.

2.2.5 Oilspills Sensor

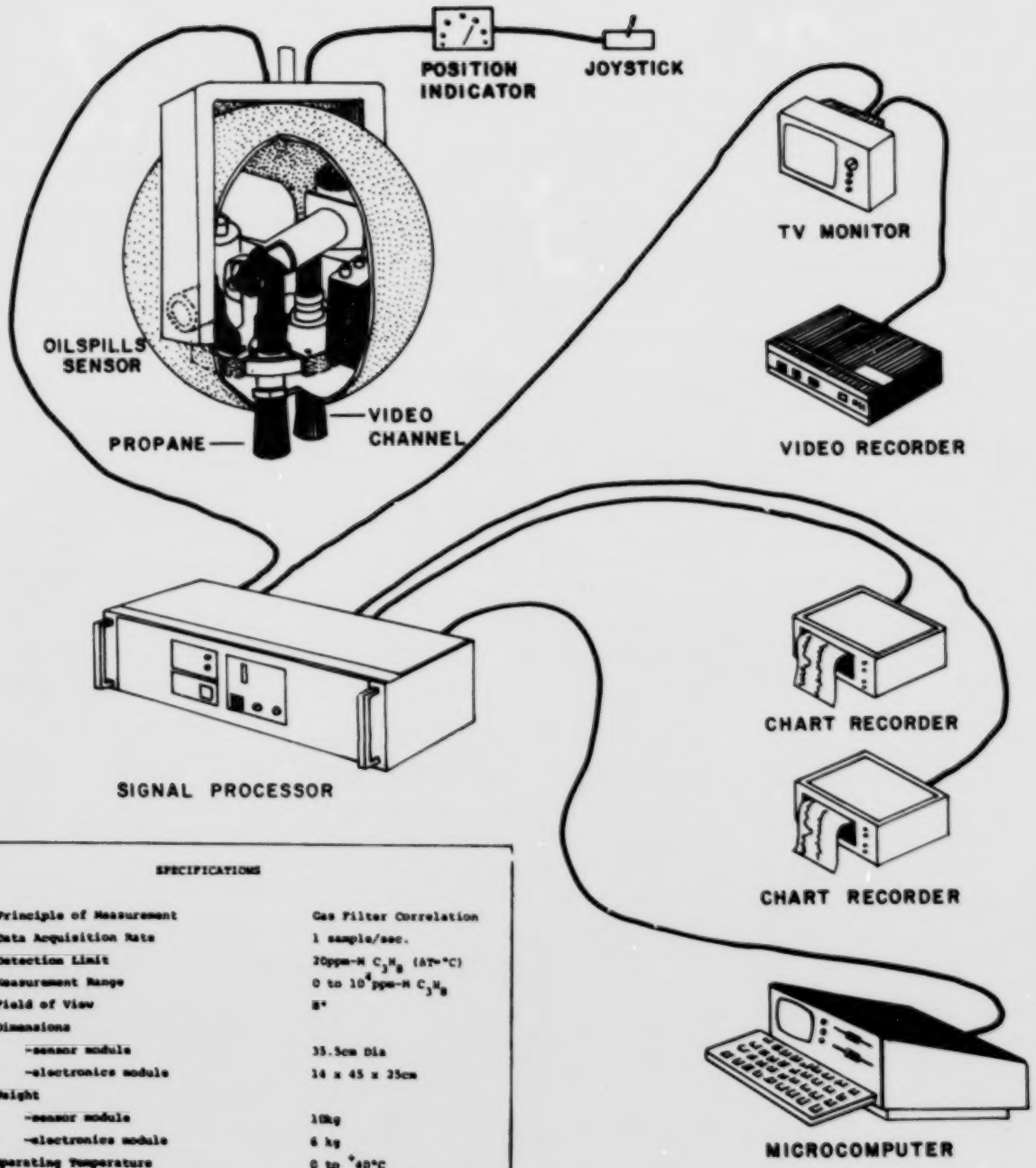
The Oilspills sensor, which operates in the IR Band, does not detect the presence of an oil slick but rather the vapour cloud resulting from evaporation of volatile fractions from the slick. The unit senses a change in spectral radiance as a result of absorption and emission of hydrocarbon vapours compared with normal background conditions.

This instrument compares radiance signals from three different sources: a reference cell, a gas cell, and a reference blackbody. The reference cell is a spectrally neutral filter while the gas cell contains a sample of the gas to be sensed. A chopper wheel rotates at 1500 rpm allowing the detector to view the three sectors sequentially. The detector produces an electronic signal proportional to the amplitude of radiation reaching it. Within the electronics module, the signals from the reference cell and gas correlation cell are balanced electronically to be the same when gas is not present in the field of view of the sensor. If the sensor is passed over an oil slick with an associated vapour plume, this balance is upset and registers as a difference in signal output.

The sensor is mounted inside a fiberglass housing and has a positionable mount. The detector is cooled with liquid nitrogen which requires refilling every three to four hours. A standard video camera is included so that the approximate detection area can be directly observed. Data are available in either digital or analog form from the electronics module. Displays can be overlayed on the video image to permit real time interpretation of results. Figure 2.4 gives a description of the sensor and associated equipment.

During this evaluation program, information was recorded on standard VCR tape with the video camera signal stored on the video track of the tape while the signals from the reference and gas channels were simultaneously recorded onto the audio track. Playback through the electronics module processes the signal back into a computer compatible format.

This sensor is most sensitive in conditions in which a large temperature contrast exists (i.e., clear, cloudless days with minimum wind speed). In principle, the sensor could operate at night but the lack of good temperature contrast due to air/surface thermal equilibrium usually results in poor signal to noise (S/N) characteristics.



SPECIFICATIONS

Principle of Measurement	Gas Filter Correlation
Data Acquisition Rate	1 sample/sec.
Detection Limit	20ppm-M C_3H_8 (ΔT-°C)
Measurement Range	0 to 10^4ppm-M C_3H_8
Field of View	8°
Dimensions	
-sensor module	35.5cm Dia
-electronics module	14 x 45 x 35cm
Weight	
-sensor module	10kg
-electronics module	6 kg
Operating Temperature	0 to +40°C
Power Requirements	28 VDC; 100 watts
Outputs	RS-232C, 7 bit ASCII, 300 Baud
	0 to 10 volt analog
	Visual/Audio Alarms
Detector Coolant	Liquid Nitrogen

FIGURE 2.4

OILSPILLS SENSOR AND ASSOCIATED ELECTRONICS

Since the sensor responds to the vapour phase rather than the oil slick, a slick must be of sufficient bulk and thickness to sustain a minimum evaporation rate for a significant period of time. For example, the evaporation rate must be .15 μm/sec where a 4°C degree temperature contrast exists. The temperature contrast which is a function of cloud cover, windspeed, and the time of day has a great influence on the detection capabilities of the sensor.

PART 3

FIELD PROGRAM DESIGN AND EXECUTION

3.0 FIELD PROGRAM DESIGN AND EXECUTION

Three elements were needed to properly evaluate the capabilities of the suite of sensors selected for the test program - a platform for the sensors, an oil source, and a suitable body of water where environmental conditions were at least partially representative of those encountered offshore. The platform had to be manoeuverable in the horizontal and vertical planes over the water and operatable at a height comparable to that at which sensors would be mounted on an offshore platform or vessel. Oil of variable type and quantity was to be available but not posing a threat to the surrounding environment. The water body had to be exposed to realistic wave and illumination conditions.

These are discussed more fully below.

3.1 SITE DESCRIPTION

The site chosen for the evaluation program was the Imperial Oil Refinery situated in Dartmouth, Nova Scotia on the east side of Halifax Harbour. The location of the refinery is shown in Figure 3.1. The testing was conducted over a boomed area surrounding the outfall from the API separators located at the southern end of the refinery property. A plan view of the site is shown in Figure 3.2. The API separators are used to treat oil contaminated process water, surface runoff from the refinery, and ballast water discharged by tankers. The effluent from the separator is discharged near the high water mark into an area of the harbour surrounded by a permanent oil containment boom. The work platform onto which the sensors were mounted was positioned onshore as shown in Figure 3.2. In this position the sensor array could be swung over both the boomed area and adjacent waters to permit viewing in both areas simultaneously.

Cables from the sensors were fed into a nearby trailer which housed the video monitors and recording equipment.

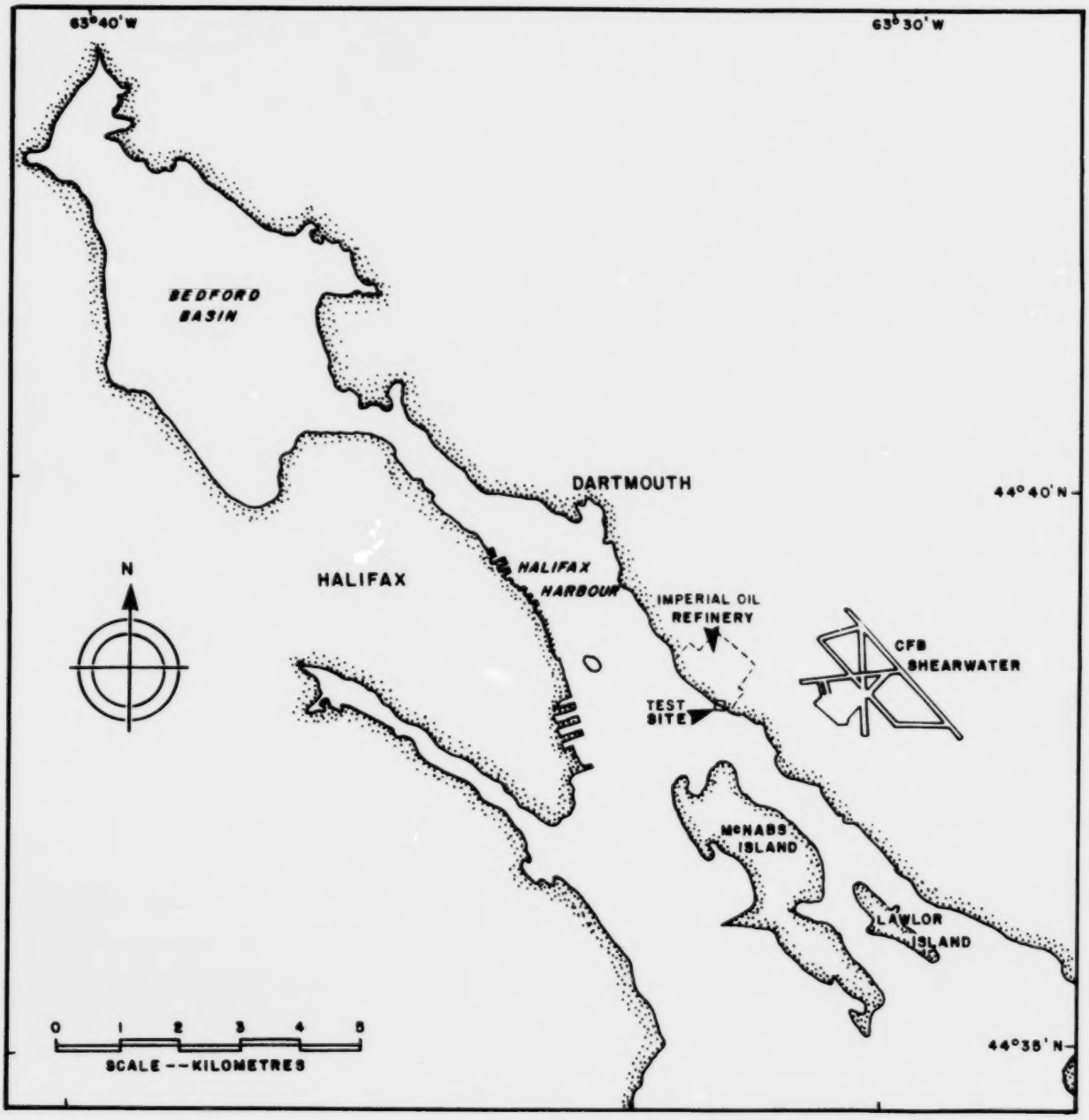


FIGURE 3.1

LOCATION OF TEST SITE

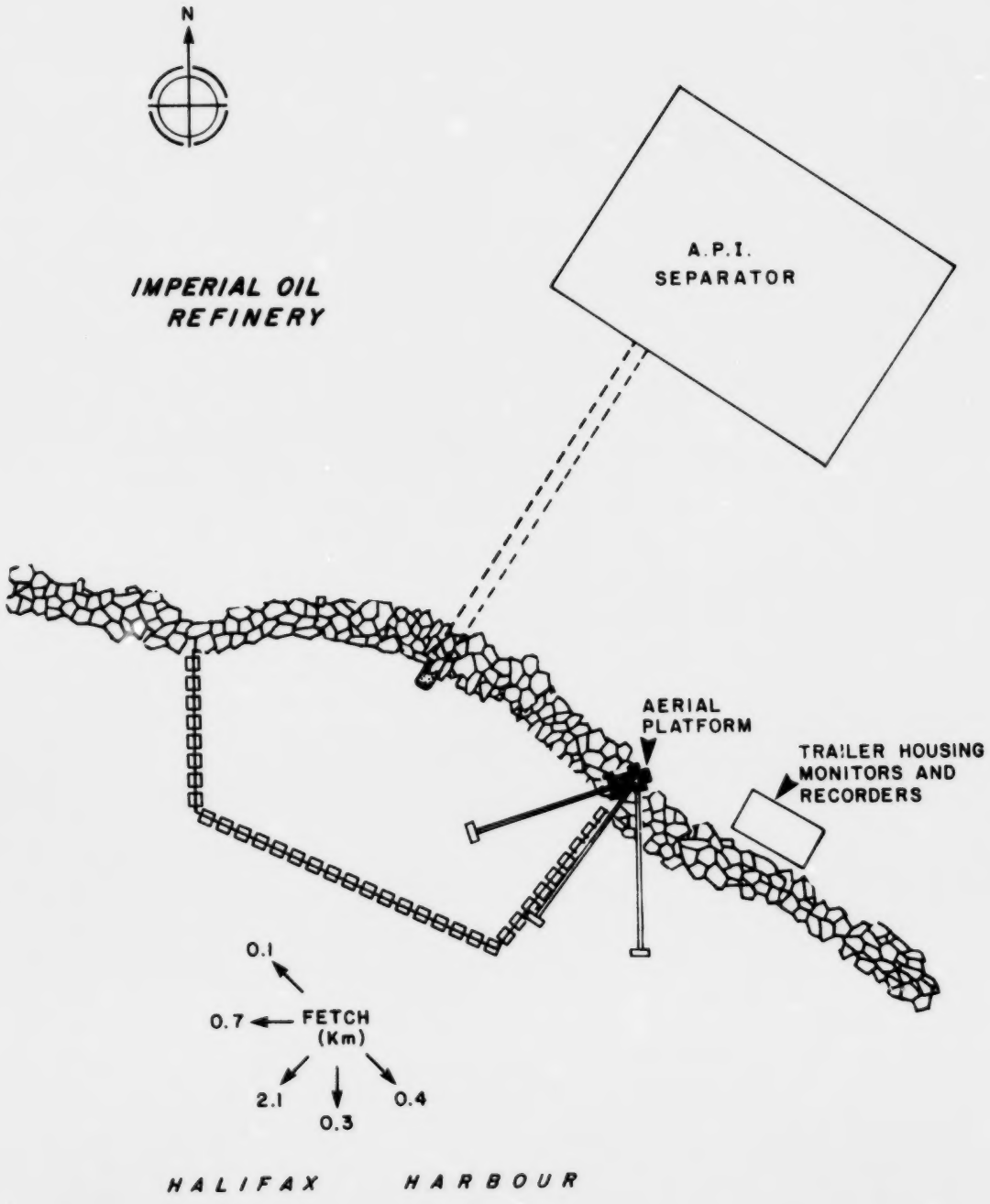


FIGURE 3.2

SITE LAYOUT

3.2 PLATFORM CONFIGURATION

The platform on which the sensors were mounted was a self-propelled aerial work platform (see Figure 3.3). The platform was normally operated at either 20, 15, 10, 5 or 3 metres above the water surface with the sensors looking vertically downwards. Sensor angles up to 45° off the vertical were obtained by tilting the platform.

The machine could be operated from either the ground or the platform and offered the flexibility required for the evaluation program. The most common operating configuration during the test program included one person inside the trailer viewing the monitors and operating the recorders and requesting the individual on the aerial platform to conduct different tests such as changing filters, sensitivities, focus, etc. Once optimum conditions were attained, the person on the platform could bring it down and then manouver it back into its previous position using the set of lower controls on the machine. Unfortunately, none of the sensors as provided were capable of complete remote operation from ground level. This meant that one person was required on the platform whenever any sensor adjustment was necessary. This proved to be time consuming and restricted the flexibility of the evaluation program.

3.3 FIELD PROGRAM

The field program began Monday, January 21, 1985 and continued for 5 weeks, ending February 22, 1985. It was broken down into two main segments as follows:

Mobilization

Sensors and support equipment started to arrive on Monday, January 21. Two weeks were spent building environmental housings for the sensors and installing them on the aerial work platform. An additional week was required to become fully familiar with sensor output and to rectify any difficulties that arose in the operation of the sensors.

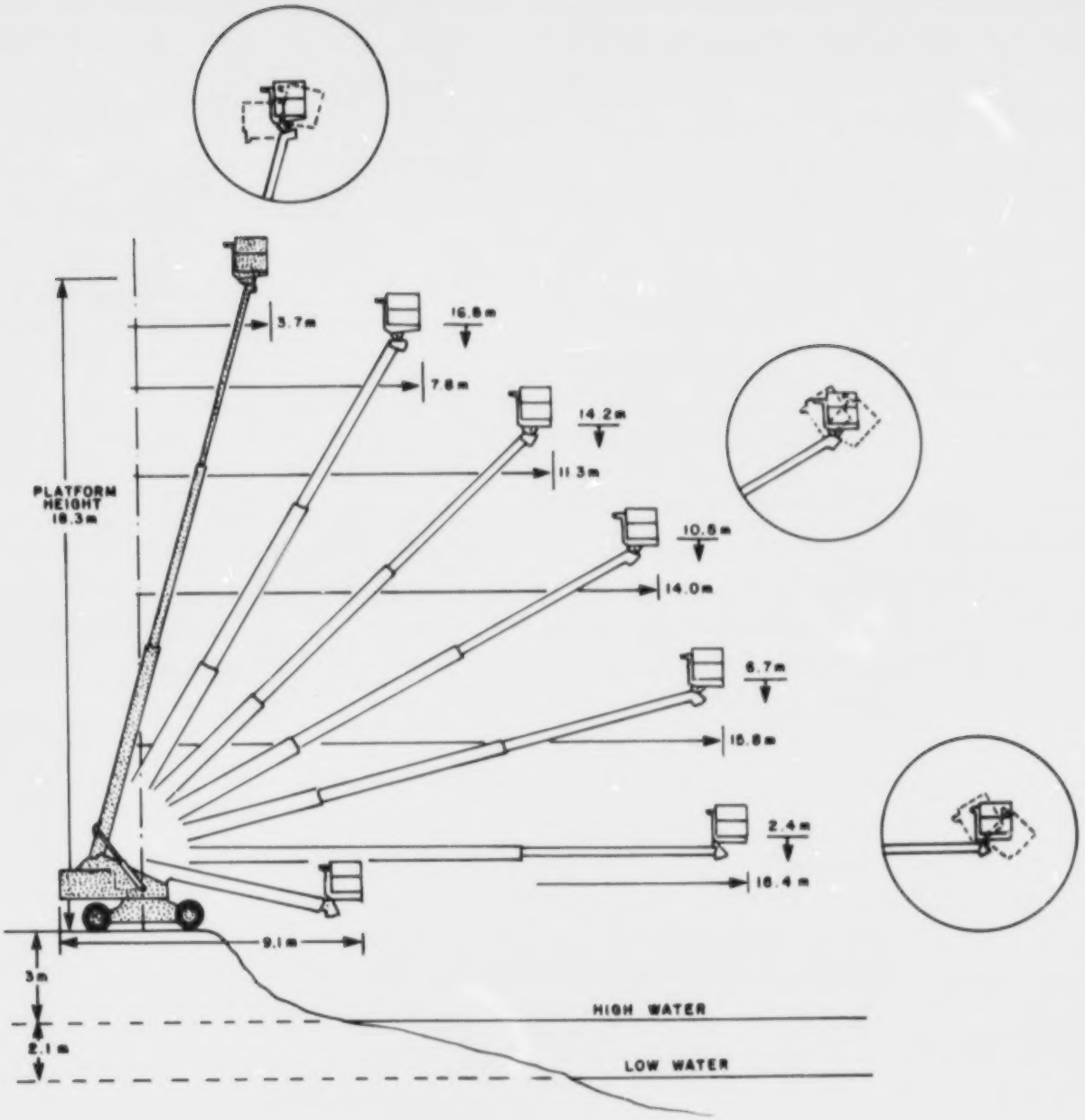


FIGURE 3.3

AERIAL WORK PLATFORM

Evaluation

The main evaluation phase of the project began February 8 and continued until February 22, 1985. Various tests of the sensors were conducted to determine their individual detection limits.

Details of the program are described below.

3.3.1 Sensor Mobilization

The equipment configuration on the platform is shown in Figures 3.4 and 3.5.

None of the sensors came equipped with complete environmental housings, so units were designed and constructed to protect the sensors and associated electronic equipment from rain, snow, and temperature extremes. Photographic cameras and the LLLTV were placed inside housings constructed of 15 cm PVC pipe. These were sealed on both ends and mounted inside a plywood case using adjustable mounts. These mounts allowed alignment of the cameras so that both would encompass the same field of view.

The photographic cameras were both provided with motor drive mechanisms to advance the film. Long shutter release cords were led down to the trailer to permit remote release of the shutter mechanisms. Since the cameras required manual focussing, this adjustment had to be conducted by either an individual on the platform or while the platform was on the ground. Graduations on the camera lens were adjusted to correspond with the operating height of the platform. No compensation in focussing was made due to the use of the filters.

The Barr and Stroud Infrared Imager was mounted without a housing on the front of the aerial work platform. The high pressure air bottle was mounted inside its shipping box and the transformer and control unit were mounted inside another plywood box on the platform.

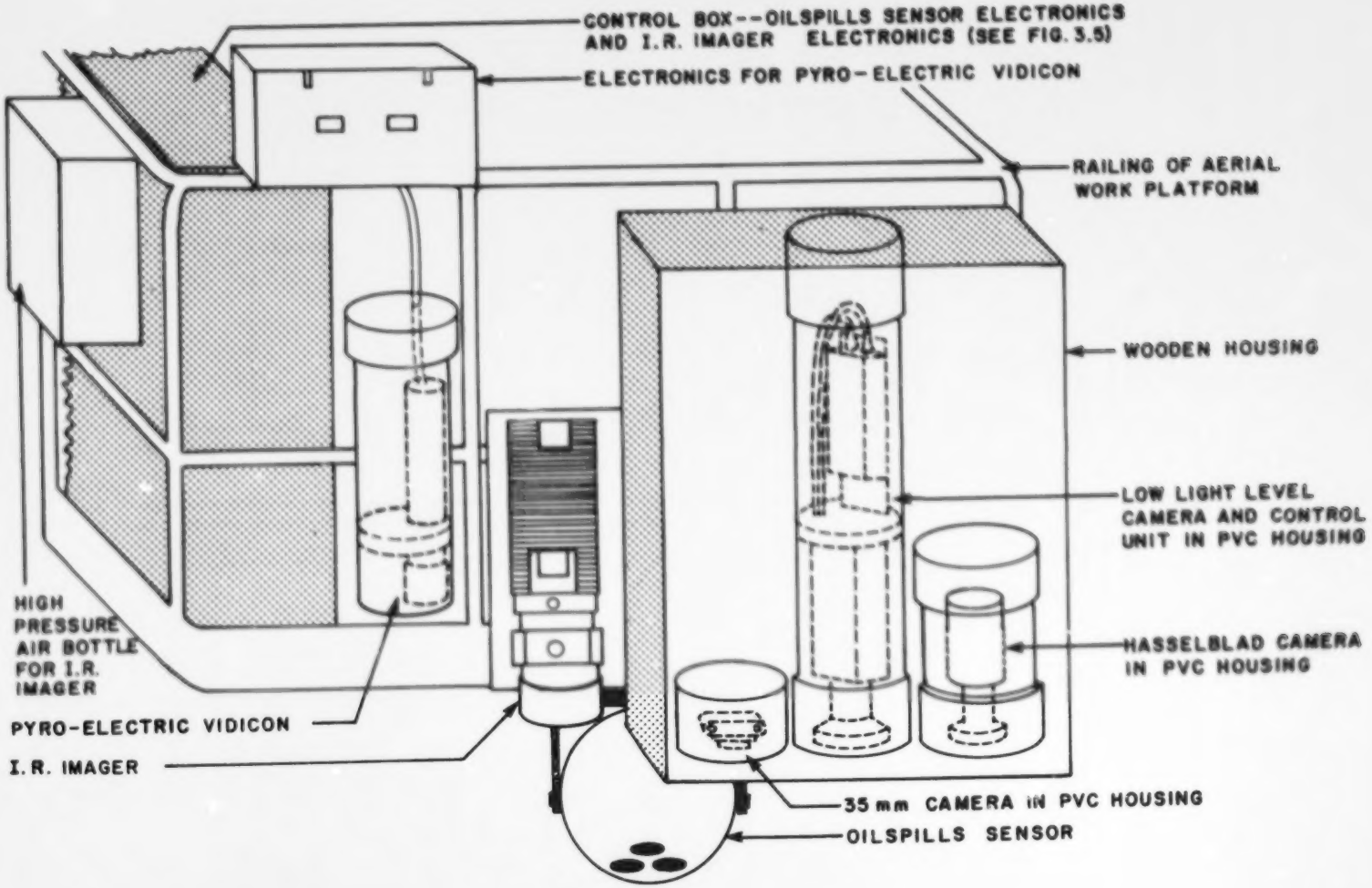

CONTROL BOX--OILSPILLS SENSOR ELECTRONICS AND I.R. IMAGER ELECTRONICS (SEE FIG. 3.5)
ELECTRONICS FOR PYRO-ELECTRIC VIDICON
RAILING OF AERIAL WORK PLATFORM
WOODEN HOUSING
LOW LIGHT LEVEL CAMERA AND CONTROL UNIT IN PVC HOUSING
HASSELBLAD CAMERA IN PVC HOUSING
HIGH PRESSURE AIR BOTTLE FOR I.R. IMAGER
PYRO-ELECTRIC VIDICON
I.R. IMAGER
35 mm CAMERA IN PVC HOUSING
OILSPILLS SENSOR

FIGURE 3.4

SENSOR CONFIGURATION ON PLATFORM

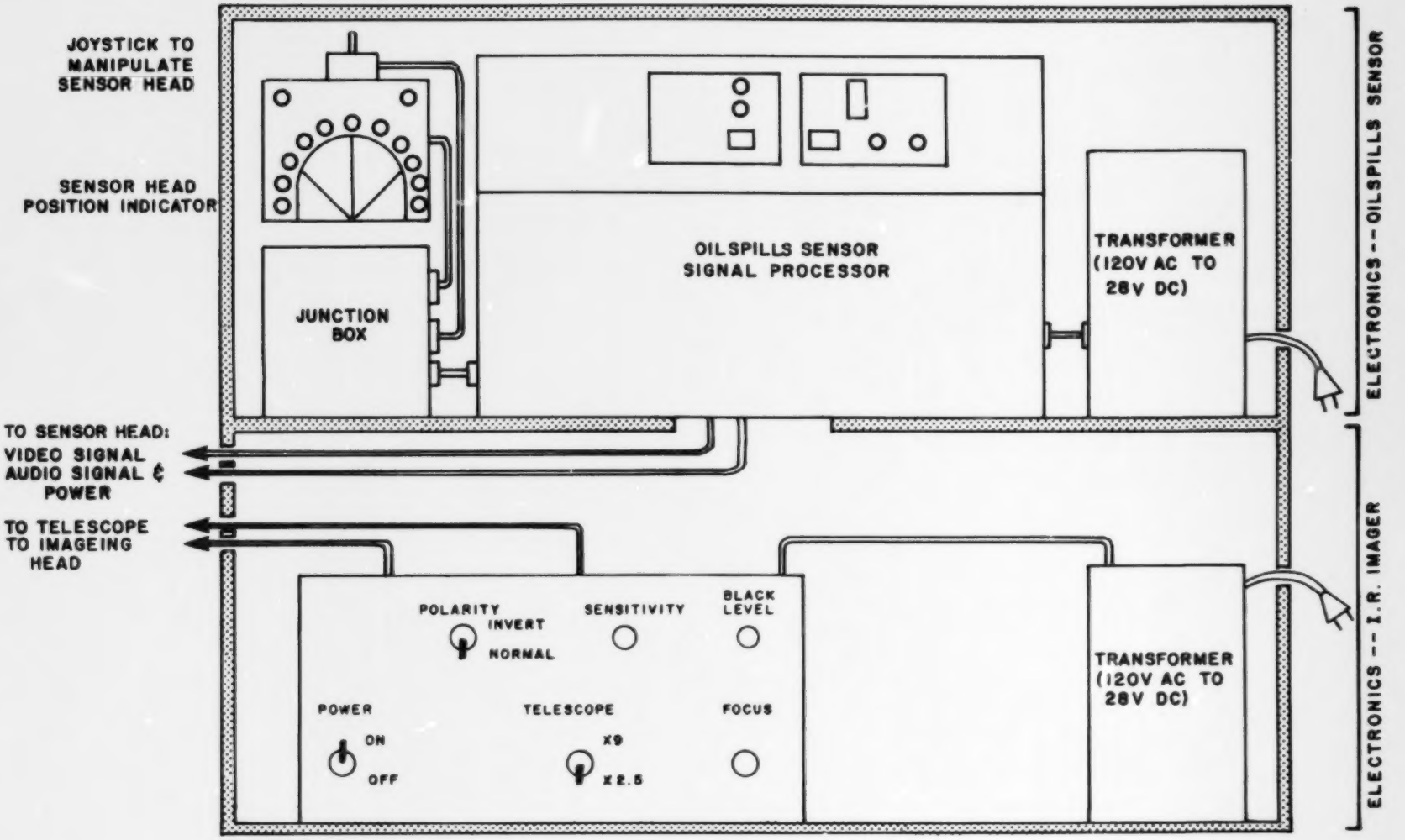


FIGURE 3.5

CONTROL BOX FOR OILSPILLS AND BARR AND STROUD IMAGER

The Barr and Stroud Infrared Imager was the only sensor tested which was capable of complete remote operation. All controls are available on the control unit which is attached by cables to the sensor head. Although this is the preferred configuration, the cables connecting the two were not long enough to reach down to ground level. There were no graduations on most of the controls which forced all adjustments to be made in real time. For instance, focus and black level adjustments could not be set before the platform was sent aloft, but had to be made at the height at which the platform was operating. The other controls did not require as much adjustment and were set as indicated below:

Polarity - set to normal (white is hot)
Telescope - 2.5 X
Sensitivity - 2°C dynamic range.

The Pyro-Electric Vidicon was mounted inside an aluminum tube fitted with a germanium window at one end. The power transformer and signal processor were mounted on an aluminium box on the platform. The only adjustment required for this sensor was focussing which was adjusted manually according to the graduations on the lens.

The Oilspills sensor was installed underneath the platform using its adjustable mounting. The associated transformer, electronics, and the position indicator and joystick to control the adjustable mount were located inside the plywood box on the platform.

The Oilspills was calibrated in the laboratory immediately prior to shipment. The calibration involved a three-stage procedure which adjusted various factors contained in the program software. A brief summary of these steps follows:

a. Using an adjustable temperature blackbody, the sensor was adjusted so that changes in radiance over the temperature range -10°C to +40°C did not result in variation in the gas channel signals;

b. Using a one-metre long gas cell, propane gas was introduced at known concentrations and a plot of gas concentration versus output voltage was developed;

c. The gas cell was vacated and methane was injected. Software parameters were adjusted so that the sensor became insensitive to this gas. This step was necessary since methane may be present in some geographical areas and could result in false signals.

The only adjustment made at the site was the changing of the gain. It is software controlled and was changed with the use of a microcomputer.

The colour camera incorporated into the Oilspills has auto-iris capability and fixed focus, neither of which permitted adjustment.

Video output cables from the LLLTV, Pyro-Electric Vidicon, Barr and Stroud Infrared Imager and Oilspills were led from the platform down to the trailer. As well, the release cables from the two photographic cameras were run down the platform and the shutter release buttons mounted in the trailer.

The video recorders, video monitors, switching mechanisms, chart recorders, and colour video camera with title generator were installed in the trailer. The basic configuration of all the major equipment used is shown in Figure 3.6.

The video equipment was set up so that each sensor with video output had a dedicated monitor and recorder. The title generator on the colour camera was used to write important information directly to the recording tape. Information included the time, date, platform height and the vertical look angle of the sensors. It was also useful in indicating when photographs were taken. The colour camera was also used to obtain an overview of the environmental conditions. Wave conditions and local visibility were easily shown by panning across the site. The system worked well

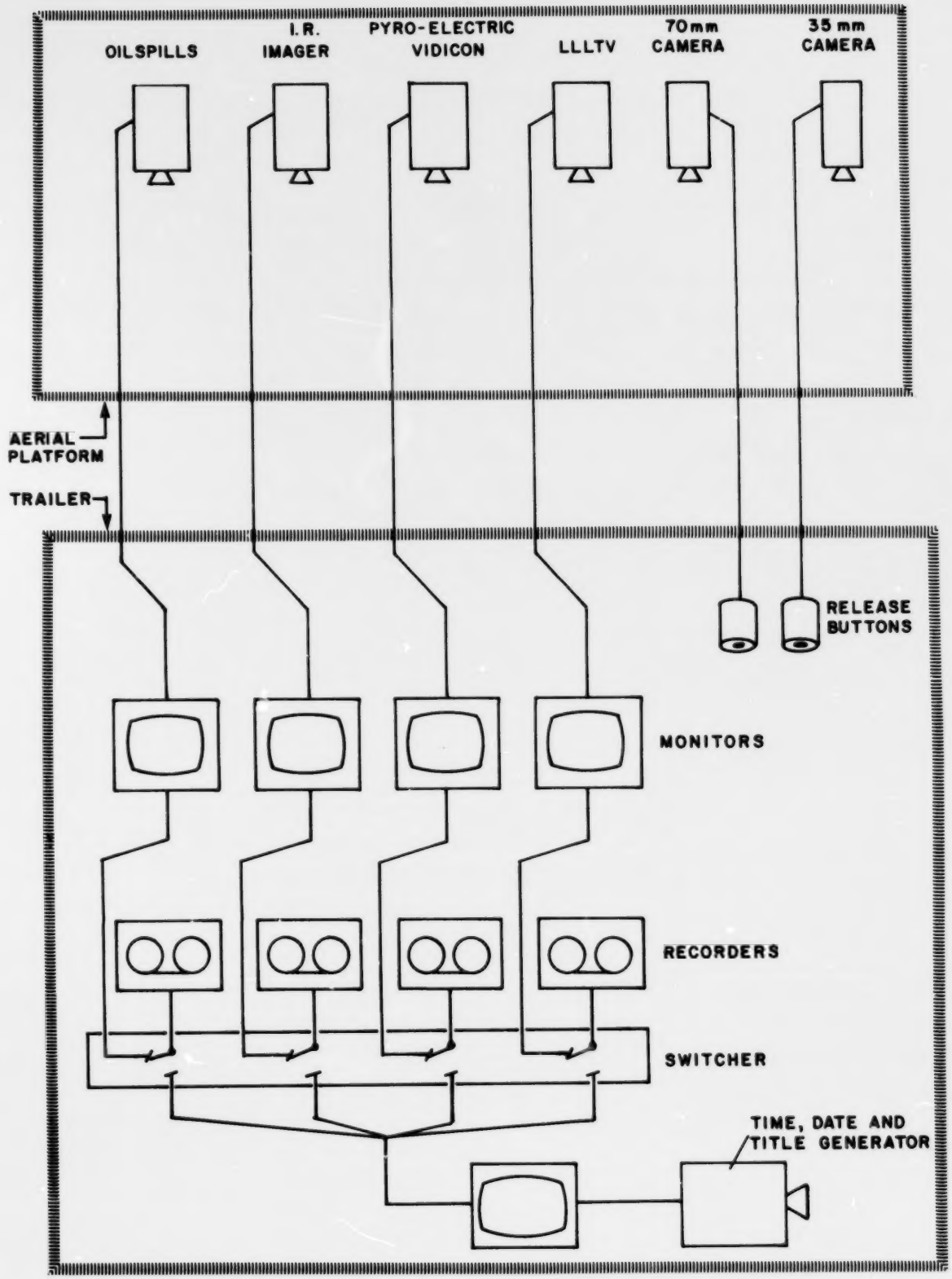


FIGURE 3.6

EQUIPMENT CONFIGURATION

except that information from the sensors was lost for short periods while the recorders were switched to record data from this camera.

3.3.2 Sensor Operation and Evaluation

The normal operating configuration for the evaluation program involved an operator on the aerial platform and another person inside the trailer operating the recording equipment. The individual in the trailer communicated via radio to the operator on the platform to request various operations such as:

- Initial alignment of sensors;
- Correct positioning of platform over the test area;
- Angle (tilt) of the platform;
- Adjustment of focus, sensitivities and black levels on sensors; and
- Changes of filters and film in photographic cameras.

Once the system was fully operational, the platform was positioned above the oil slick present within the enclosed area and all sensors were aligned. This permitted comparison between the oil detection limits of the various sensors. Slick thickness measurements were undertaken by lowering a surface slick sampler onto the oiled surface from the platform. Slick thickness measurements could then be used to verify sensor output and determine the detection limits of the individual sensors.

When no oil was present due to lack of oil discharge from the refinery, small quantities of oil were released onto the water surface within the enclosed area.

Knowledge of the volume of oil released and the surface area covered by the oil slick as it spread out allowed a fairly accurate estimation of mean slick thickness.

Height of the sensor package above the water surface was measured by lowering a secchi disk with a graduated rope from the platform to the water surface. When the sensor array was positioned over the water, the disk was also used as a stationary feature from which to compare outputs of the different sensors. It was also useful for gaining an indication of water transparency.

3.3.3 Environmental Observations

Environmental observations during the test program were necessary since the detection of oil with most sensors is dependent on the environmental conditions present at the time of observation. A complete set of environmental observations was therefore necessary for a fair evaluation of the oil detection capabilities of each sensor. The records obtained from Shearwater Airport located 3 km SSE of the test site provided this necessary information. The short distance between the two locations ensured that most of the observations taken at Shearwater Airport were representative of those present at the test site. Observations taken at the site were used to supplement those available from the airport.

Table 3.1 provides a brief summary of the weather conditions experienced from February 8 to February 22, 1985, which encompasses the main evaluation phase of the program. Included in Table 3.2 are the daily values for temperature, relative humidity, precipitation, wind, and solar insolation recorded at Shearwater over this period.

3.3.4 Ground Truthing

Visual observations and actual measurements of slick thickness were made and the composition of the slick was determined. Visual observations

TABLE 3.1

DAILY WEATHER SUMMARY
FEBRUARY 8 TO FEBRUARY 22, 1985

Date	Conditions
February 8.	Sunny, becoming cloudy in the afternoon. Extremely cold.
February 9.	Cloudy with flurries. Mild.
February 10.	Cloudy with a few flurries. Mild.
February 11.	Cloudy and mild.
February 12.	Cloudy with a few flurries.
February 13.	Periods of snow, freezing rain and rain. Turning very mild in the evening.
February 14.	Rain ending 3:50 a.m., becoming sunny in the afternoon. Showers 10:35 a.m. to 10:55 a.m. Fog. Very mild.
February 15.	Overcast. Flurries and showers in the afternoon and evening. Mild.
February 16.	Cloudy. Periods of snow in the early morning. Mild.
February 17.	Cloudy. Flurries beginning late evening. Mild.
February 18.	Sunny. Ice pellets and snow in early morning. Flurries 4:32 p.m. to 6:30 p.m. Mild.
February 19.	Sunny, becoming overcast in the afternoon. Flurries late afternoon and evening.
February 20.	Sunny, becoming cloudy in the afternoon. Flurries in the late evening. Mild.
February 21.	Mainly sunny and cold.
February 22.	Overcast. Showers and drizzle in the afternoon and evening. Turning mild in the evening.

TABLE 3.2

METEOROLOGICAL SUMMARY AT SHEARWATER AIRPORT
FEBRUARY 8 TO FEBRUARY 22, 1985

Latitude: 44°38'
Longitude: 63°30'

Elevation 54.3 m ASL

DATE	TEMPERATURE			RELATIVE HUMIDITY		PRECIPITATION			WIND		
	°C	°C	°C	%	%	mm	mm	mm	km/h		Hours
8	-11.5	-16.0	-13.8	76	58	0.0	TR	TR	24.8	W	6.2
9	2.4	-12.7	-5.2	97	76	0.0	TR	TR	20.0	NNW	1.0
10	2.5	-.9	.8	95	77	0.0	TR	TR	27.3	NNW	3.7
11	2.2	-3.5	-.7	93	68	0.0	0.0	0.0	20.9	N	4.2
12	-2.0	-4.2	-3.1	96	88	0.0	TR	TR	8.8	ESE	0.0
13	4.3	-3.8	.3	100	93	31.2	.2	31.4	33.9	E	0.0
14	4.5	-.5	2.0	100	90	2.2	0.0	2.2	8.0	S	2.6
15	2.7	-.2	1.3	100	84	.8	3.8	6.0	8.0	S	.3
16	2.4	-1.6	.4	97	69	0.0	TR	TR	17.3	SW	5.8
17	2.0	-1.6	.2	93	71	0.0	TR	TR	14.5	S	5.7
18	2.5	-4.4	-.9	100	55	0.0	3.0	2.5	18.1	W	7.1
19	1.5	-7.1	-2.8	97	61	1.1	4.0	5.4	17.2	W	6.7
20	1.5	-5.5	-2.0	93	67	0.0	.5	.6	10.3	W	6.5
21	-4.0	-12.5	-8.3	91	54	0.0	TR	TR	15.9	NW	10.3
22	3.9	-12.4	-4.3	100	75	4.8	0.0	4.8	18.4	S	2.8

of the slick thickness were made by comparing observed conditions with colour plates contained in Fingas et al. (1979).

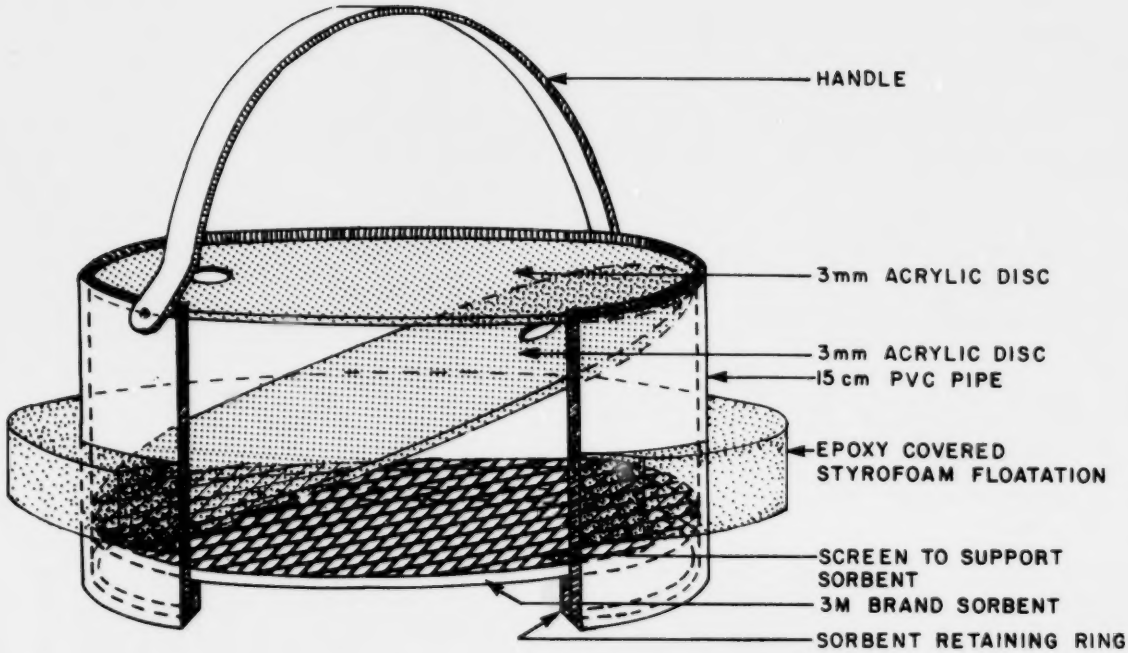
Physical measurements of slick thickness were obtained using a Belore Sampler as illustrated in Figure 3.7. The Belore Sampler is an open ended PVC cylinder into which a piece of 3M sorbent is placed. When the sampler is dropped into the slick, the "cookie cutter" edge traps a known surface area of the slick which is absorbed and retained by the sorbent liner. For very thin slicks, repeated applications with the same sorbent sheet were made to collect a sufficient sample for analysis.

The oil was extracted from the sorbent using 100 ml of methylene chloride and dried with anhydrous sodium sulfate to separate the oil from the water. The volume of the oil was determined using a colorimetric technique using a Bausch and Lomb Spectronic 20 spectrometer. A standard was prepared from one of the refinery stock oils (Alberta Sweet Mix Blend) and measured for percent absorption. A standard graph was plotted and the amount of oil in each sample was calculated as follows:

$$\text{Slick Thickness} = \frac{\text{Vol. of Oil}}{\text{Area of Sorbent in Sampler}}$$

Sixteen samples were collected. The results are shown in Table 3.3. The slicks ranged from 0.1 to 10.7 µm in thickness with the majority of the slicks being less then 1.0 µm. Visual estimates generally corresponded well with measured values when slick thicknesses were less than 2.0 µm.

Qualitative analysis of oil samples were done using a Varian 3700 Gas Chromatograph equipped with a Flame Ionization Detector. Samples were taken from the API separator and those with a low concentration of oil were extracted with 30 ml of dichloromethane and the solvent removed on a rotary evaporator at reduced pressure. For samples greater than 50% oil, the sample was frozen to solidify the water and permit decanting of the oil. The samples were injected directly into the gas chromatograph operating



(NOT TO SCALE)

FIGURE 3.7

BELORE OIL THICKNESS SAMPLER

TABLE 3.3

SLICK THICKNESS MEASUREMENTS IN OR NEAR THE BOOMED AREA

Date	Time	Location	Thickness (μm)
February 11	Morning	Inside Boom	0.3
February 11	Morning	Inside Boom	0.3
February 11	Morning	Inside Boom	10.7
February 11	Morning	Inside Boom	2.2
February 12	Morning	Inside Boom	1.3
February 12	Morning	Outside Boom	0.2
February 18	0950	Inside Boom	5.3
February 18	0955	Inside Boom	0.28
February 18	1520	Inside Boom	0.52
February 18	1540	Inside Boom	0.5
February 20	0917	Inside Boom	0.1
February 20	1612	Inside Boom	1.2
February 20	1613	Inside Boom	0.16
February 22	1603	Inside Boom	0.5
February 22	1612	Inside Boom	0.5
February 22	1614	Inside Boom	0.24

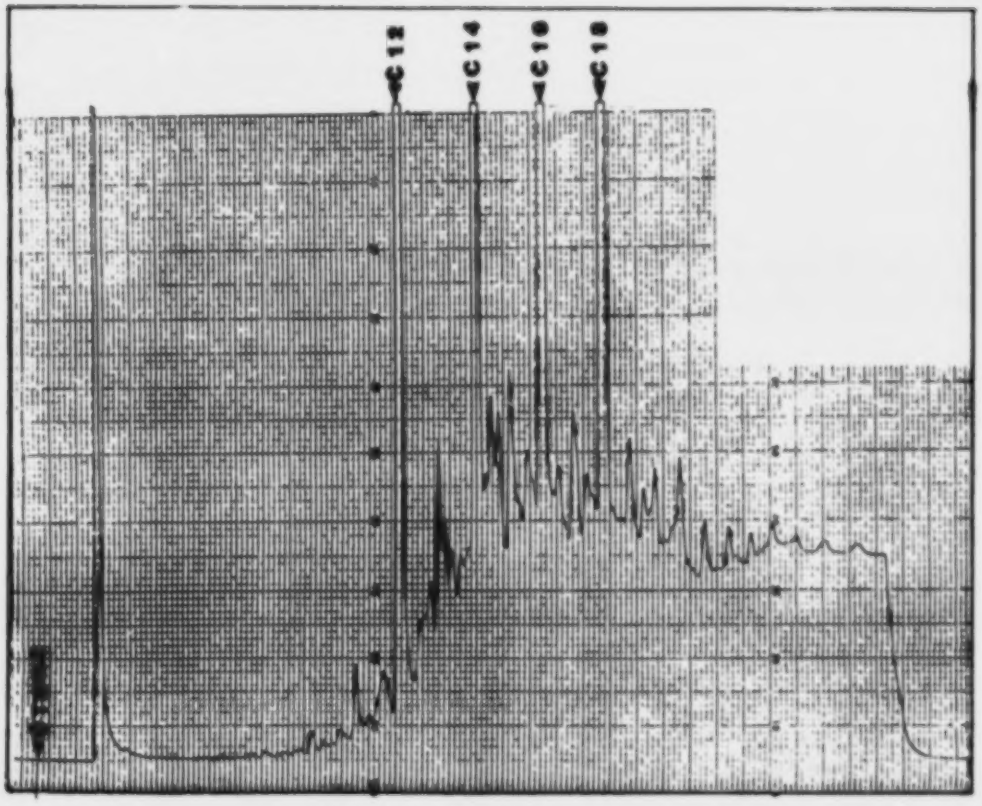
under the conditions noted below. A n-parrafins (C_n) standard was run to identify peaks.

The plots from the GC analysis are presented in Figures 3.8, 3.9 and 3.10. A summary of oil characteristics follows:

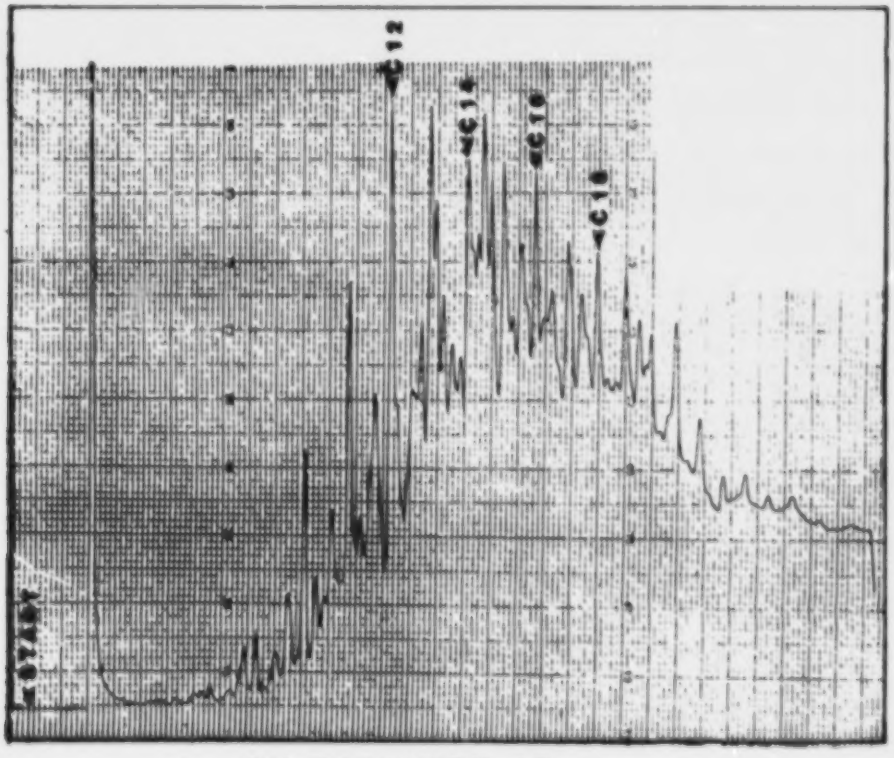
February 15	Slightly weathered crude
February 17	More heavily weathered crude
February 18	Indication of higher boiling point ends of cracked crude
February 20	Slightly weathered crude
February 22	Slightly weathered crude

The samples all appeared to contain weathered low boiling point crude oil with no evidence of paraffins above C_{28} to C_{30}. The gas chromatograms indicate that the volatile fractions below C_{12} were missing in most of the samples collected.

On many occasions, samples indicated that the oil in the lagoon existed not only as a slick, but also as small buoyant globules that floated at or just below the water surface.

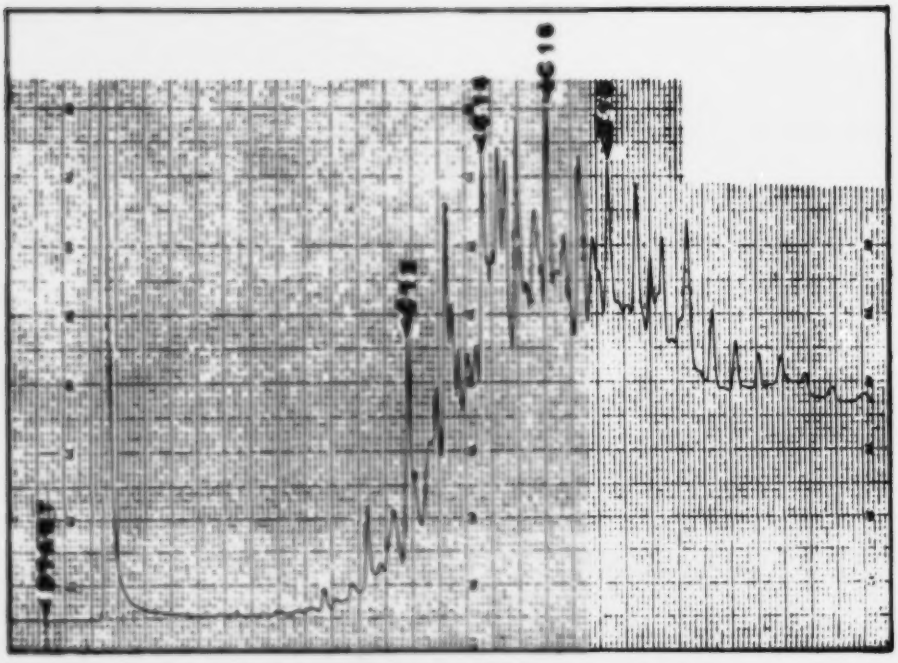


(A) STANDARD

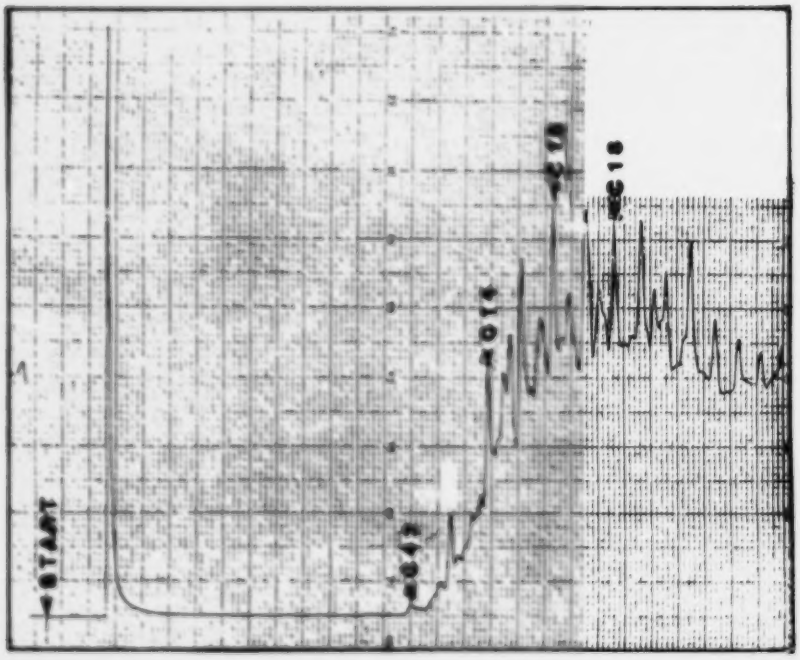


(B) FEBRUARY 15

FIGURE 3.8
GAS CHROMATOGRAMS OF OIL SAMPLES

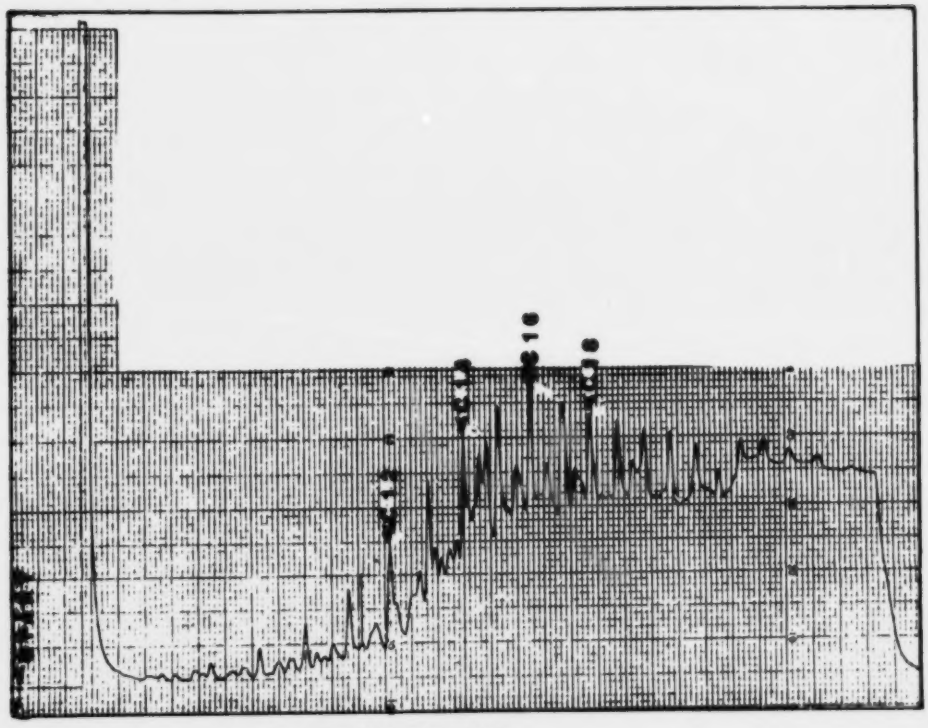


(A) FEBRUARY 17

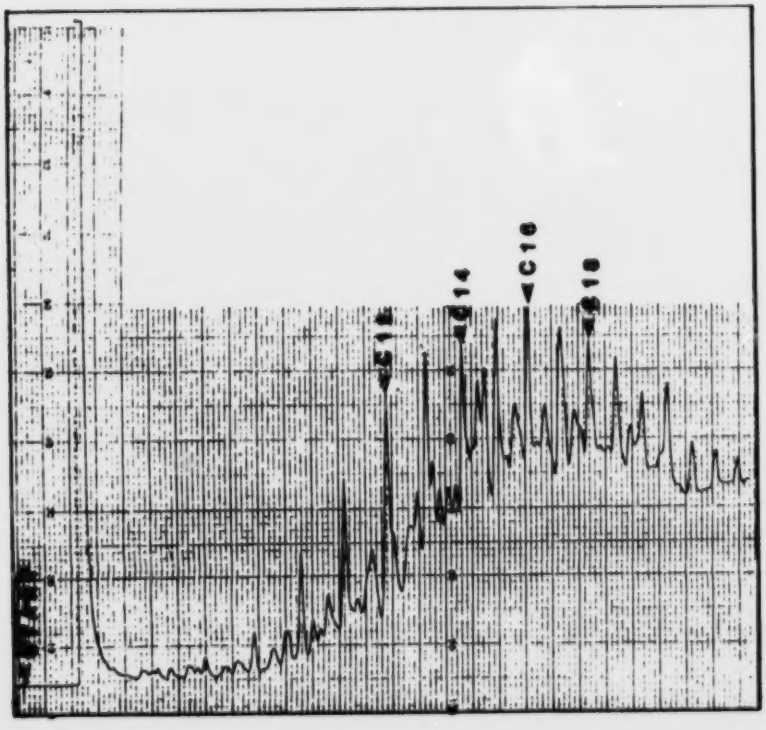


(B) FEBRUARY 18

FIGURE 3.9
GAS CHROMATOGRAMS OF OIL SAMPLES



(A) FEBRUARY 20



(B) FEBRUARY 22

FIGURE 3.10
GAS CHROMATOGRAMS OF OIL SAMPLES

PART 4

SENSOR PERFORMANCE

4.0 SENSOR PERFORMANCE

This section of the report contains the results of the field program and an assessment of the detection capabilities and performance of each of the sensors evaluated. The discussion of the performance of each sensor package is broken down into two sections:

- Factors affecting oil detection, and
- Parameters affecting sensor operation.

Where possible, results obtained from other units are used to compare and contrast the results.

4.1 PHOTOGRAPHIC CAMERAS

In general, the photographic cameras were able to detect the presence of oil on water under most conditions encountered in the study. However, a number of operational problems with the cameras resulted in a poor rate of data recovery, particularly during the early stages of field trials.

4.1.1 Factors Affecting Oil Detection

As predicted, the higher reflectance of oil compared with that of water in the near UV was sufficient to provide adequate contrast for the cameras to discriminate between the two media. The factors which were observed to have the greatest effect on the oil/water contrast were sky conditions, wave conditions and slick thickness.

The contrast between the oil and water was found to be greatest under clear skies during the middle part of the day when the amount of UV radiation is at a maximum. An example of the effect of how sky conditions can affect the oil-water contrast is shown in Figures 4.1 and 4.2. Both pictures were taken with an unfiltered 35 mm camera using B & W film, from

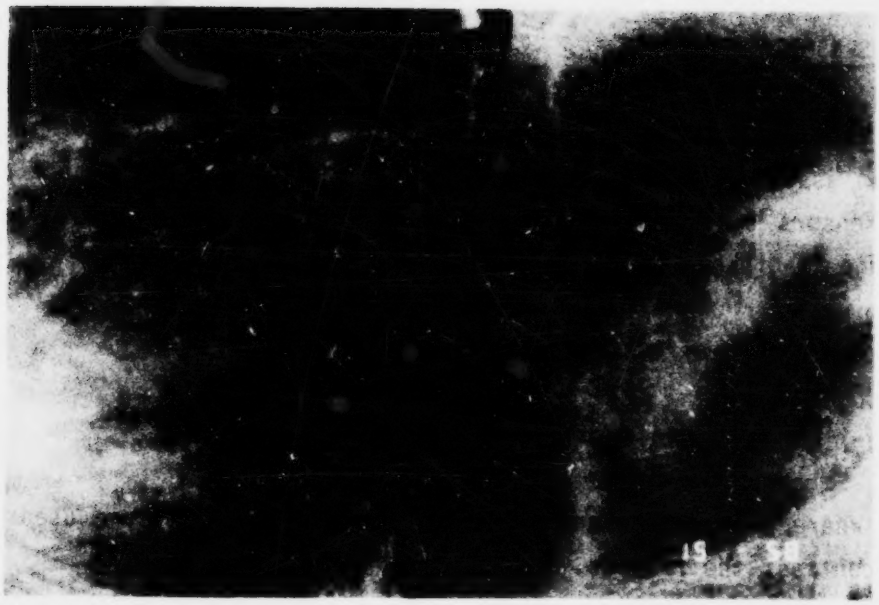


FIGURE 4.1

**35mm BLACK AND WHITE PHOTOGRAPH (UNFILTERED)
CLOUD COVER, ALTITUDE OF 20m**

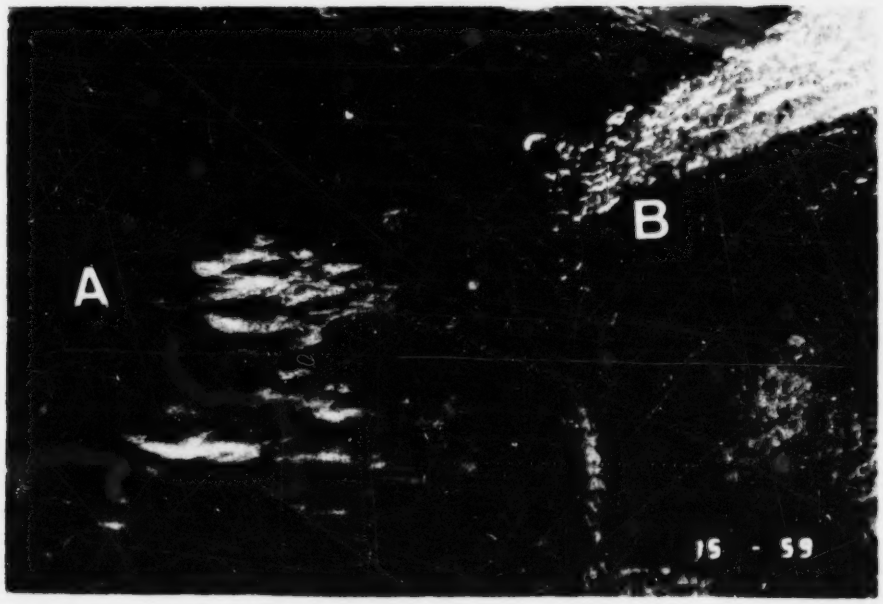


FIGURE 4.2

**35mm BLACK AND WHITE PHOTOGRAPH (UNFILTERED)
REDUCED CLOUD COVER, ALTITUDE OF 20m**

a height of 20 m above the water. The pictures were taken one minute apart during a change in sky conditions. They have a slightly different areal coverage due to a small change in sensor viewing angle, but the important feature is the difference in oil/water contrasts. The reduced contrast evident in Figure 4.1 is the result of cloud cover reducing scene iliumination and the absorption of UV.

Figure 4.3 was taken with the UV filtered 2 1/4 in. format camera, at the same time as Figure 4.2. The pictures look quite similar except that the UV filtered photo detects thinner sheens than the unfiltered photograph. At locations A and B marked on Figure 4.2, no oil is seen; however, in Figure 4.3, oil is evident at these locations. By restricting the spectral range to the UV, the higher reflectance in this region allows the detection of thinner slicks.

The environmental parameters at the time of the photos included broken cloud cover (6 to 9/10ths) with 6 m/s winds blowing from the right of the photographs. The outfall is to the right of the photo. The wind is blowing the oil towards the left where it is being trapped against the boom. The oil present to the left of the boom represents leakage underneath the boom. This thinner oil appears brighter than the thicker oil to the immediate right of the boom due to lower absorption of the volume reflected radiation component. The thicker slicks have a reduced volume reflected radiation component and therefore appear darker than the thin slick, although they are still lighter than the adjacent water. Excluding total darkness, no conditions were experienced during which oil could not be sensed with the photographic cameras. Slicks as thin as 0.1 μm were detectable, particularly with the UV filtered large format camera.

Glitter from the water surface was evident, although at no time did it seriously diminish the overall quality of the imagery. Glitter could reduce the usable information contained in a photograph. However, as long as it is discontinous, adequate information could be obtained from other portions of the photograph. Severe glitter problems occur when the camera is directed at the sunlight reflected from the water surface.

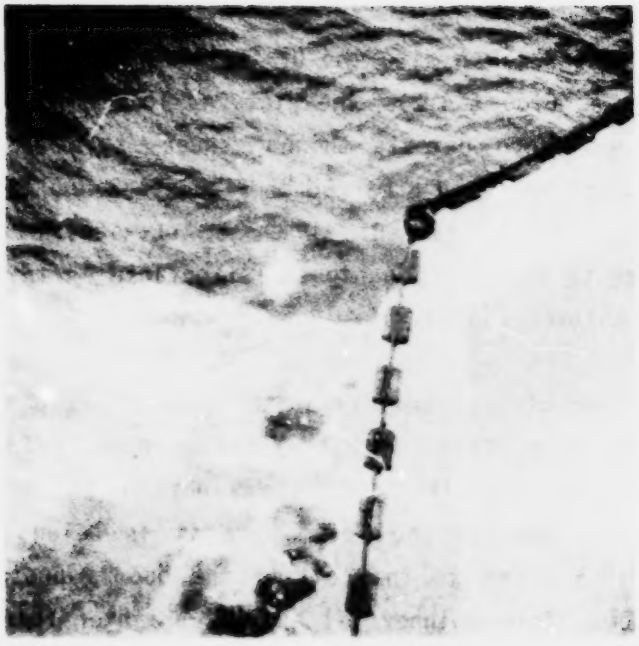


FIGURE 4.3

HASSELBLAD PHOTOGRAPH (UV FILTERED)
BROKEN CLOUD COVER, ALTITUDE OF 20m

Slicks may be detected within the sun's glitter pattern since they appear dark due to a dampening of the capillary waves by the oil. This method of discrimination is not considered feasible for offshore applications due to restrictions on camera, sun, and platform orientation. The limited height of an offshore platform would only allow slicks of very limited areal extent to be detected using this method.

4.1.2 Parameters Affecting the Sensor Operation

Although a number of operational problems were experienced, the photographic cameras performed well. The main difficulty resulted from the low temperatures experienced during mobilization of the equipment. The motor drive mechanisms of the cameras proved ineffective in the cold weather but this was rectified by heating the camera housing. The long shutter release cords that led from the platform to the trailer became ineffective in the damp weather and a relay switch had to be constructed to rectify this problem.

Another problem encountered was in determining the proper exposure setting for the large format camera outfitted with UV filter. The relatively low operating height of the platform, combined with considerable wave action, demanded a fairly fast shutter speed. At the same time, the UV filter severely restricts the light passing through to the film and therefore performs best at low shutter speeds. A compromise was use of a fast film and a shallow depth of field, although the film was extended beyond its optimal speed, resulting in the deterioration of image quality.

The 35 mm camera used during the tests was capable of either manual or automatic exposure settings. In the automatic mode, the shutter speed was automatically adjusted to compensate for changes in illumination conditions. Although the automatic mode was easier to operate, the manual setting provided better detection of oil since the gray tones of the water and oil do not change as drastically with changes in illumination. With the camera in automatic exposure mode, a change in illumination would

result in a faster shutter speed with a reduced oil/water contrast.

Since the photographic cameras were mainly used for documentation of results obtained from the other sensors, the results obtained are discussed further in subsequent sections as they relate to other sensor outputs.

4.2 LOW LIGHT LEVEL TELEVISION

In general, the UV filtered Low Light Level Television (LLLTV) was found to provide the best overall results for the conditions encountered during this study. The superior performance of the sensor can be attributed in part to its large field of view and its relatively simple mode of operation.

4.2.1 Factors Affecting Oil Detection

As was the case for the photographic cameras, the increased reflectance of UV light from an oil surface compared to a water surface was sufficient to allow the LLLTV to detect oil under most environmental conditions. Whereas the photographic cameras required considerable illumination to produce a good oil-water contrast, the light intensification capability of the LLLTV produced good imagery even under foggy and overcast conditions. In fact, the LLLTV performed best under these conditions. During overcast or foggy conditions, the range in contrast over the water surface is reduced because of glitter. The camera can compensate for the reduced light levels encountered under these conditions while the monitor is capable of increasing the contrast in the field of view.

Although the actual oil-water contrast is greater under clear sky conditions, the ratio of the oil/water contrast to the overall screen contrast is greater for overcast conditions.

Problems were experienced in detecting oil with the LLLTV whenever any bright object was in its field of view. When the assembly was operated

near the shore in the boomed area, snow was often seen in the field of view. The increased reflections from the snow covered surface caused the auto-iris in the camera to close down, decreasing the contrast. When it was snowing, the snow passing in front of the camera lens was sufficiently bright to reduce the sensitivity of the camera, again affecting the ability of the unit to discriminate between the oil and water.

Glitter from the water surface was the most persistent feature reducing the sensitivity of the TV camera. Previous testing with the LLLTV has involved the camera looking away from the sun at or near Brewster's angle, which is 53° from the vertical. At Canadian latitudes, this procedure is effective in virtually eliminating glitter. This, however, places severe restrictions on the placement and orientation of LLLTV sensors. Recognizing this, the field program was designed to investigate other sensor look angles and determine what would be the most practical one for offshore monitoring. The sensors were operated primarily in the vertical mode with some operation at 15, 30 and 45° off the vertical. A variety of sensor azimuth angles in relationship to the sun were also investigated.

As anticipated, glitter problems were most severe when the LLLTV was directed towards the sun with a viewing angle from the horizontal equal to the altitude of the sun above the horizon. As the horizontal and vertical look angles were moved away from this orientation, the amount of glitter received by the sensor increasingly became a function of the wave forms present on the water surface. Glitter is caused by specular reflection from the water surface and occurs whenever the plane of the water surface is normal to the bisector of the incident and reflected ray as shown in Figure 4.4.

During the recording phase of the experiments, the maximum solar altitude varied from 30° on February 8th, to 36° on February 22. Figure 4.5 shows the wave angle necessary for specular reflection to occur for a 30° solar elevation in relation to vertical sensor look angles. This is assuming the sensor's azimuth is directed towards or away from the sun.

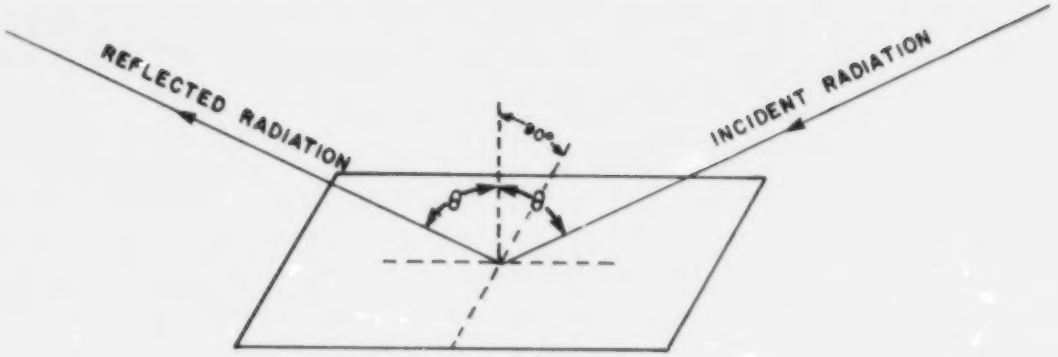


FIGURE 4.4
EXAMPLE OF
SPECULAR REFLECTION

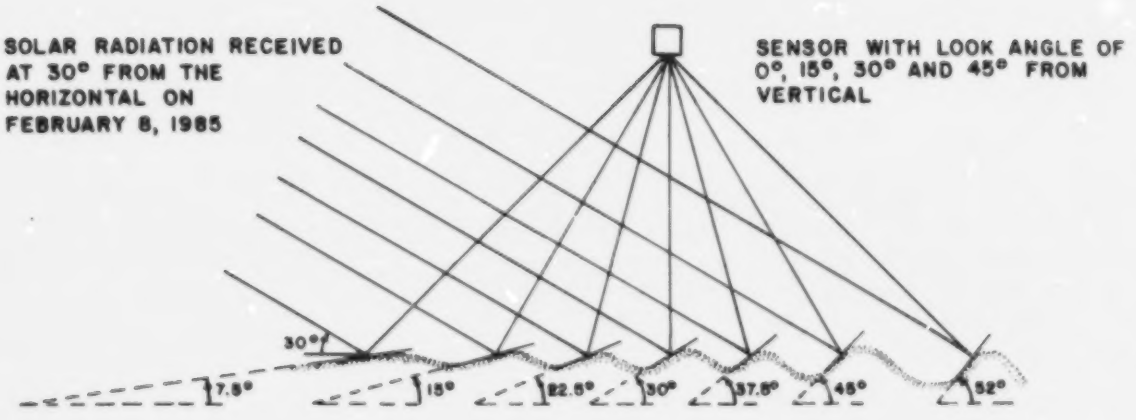


FIGURE 4.5

WAVE SLOPE REQUIRED
FOR SPECULAR REFLECTION

When the azimuth of the sensor is directed neither directly toward nor away from the sun, the wave slope required for specular reflection becomes greater than that indicated in Figure 4.4. Wave slope varies as a complex function of wind speed, varying from 0-5° under calm conditions, to 30-40° under gale force winds on the open ocean.

Figure 4.6 is an example of poor quality LLLTV imagery which results from glitter. The sensor was directed vertically downward from an altitude of 3 metres near the shoreline. Rocks along the shore are evident on the left side of the photo. The imagery was taken at 1345 local time on February 18th with 5/10ths cloud cover and unlimited visibility. The winds were from the west at 7.7 m/s. A paper cup containing 200 ml of oil collected from the API separator was dropped directly into the centre of the field of view of the LLTV. Due to the glitter it was impossible to detect any oil. Figure 4.6 is a photograph of a television monitor image. As a result, the dynamic quality of the original video imagery is lost. The figure does, however, display the gross features evident in the original imagery.

The series of photos shown in Figures 4.7 to 4.9 was taken on February 15 from a 5 m elevation with a sensor viewing angle of 30° off the vertical. The sky was overcast, visibility was 16 km and the wind speed was 1 m/s. Oil was very evident to the right of the boom. A cup containing 200 ml of oil was dropped into the water as shown in Figure 4.7. Figure 4.8 was taken two seconds after impact and shows the oil spreading out from the point of impact. Figure 4.9 was taken 25 seconds after impact and shows an areal coverage of approximately 10 m^2 with an estimated average thickness of 2.0 μm. Note that the thinner oil located around the edge of the slick appears brighter as was the case with the photographs discussed in Section 4.1.1.

Figures 4.10 and 4.11 were taken on February 20 at 1613 local time. The former was obtained with the UV filtered photographic camera while the latter was taken with the UV filtered LLLTV. The sensors were vertically oriented and were operated from a height of 20 m above the water surface.

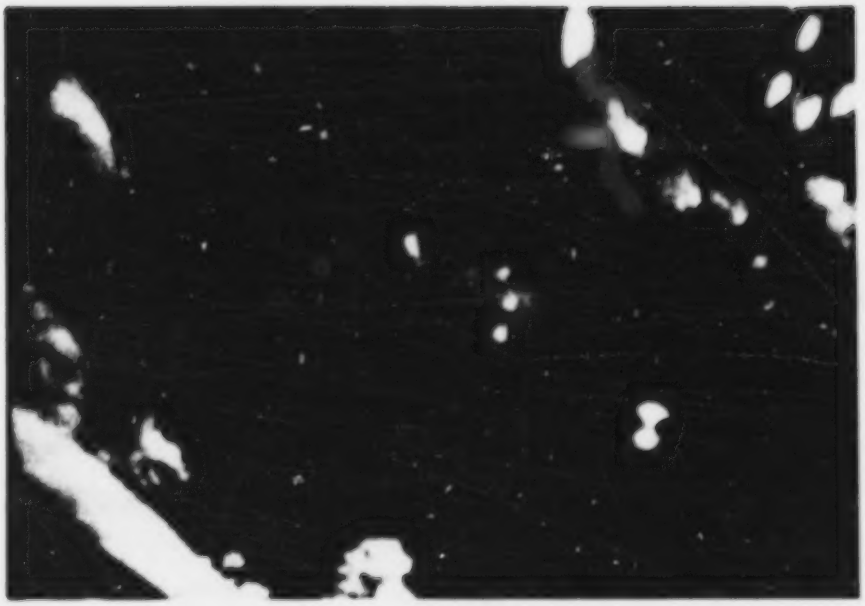


FIGURE 4.6
PHOTOGRAPH FROM LLLTV MONITOR
5/10 CLOUD COVER, ALTITUDE OF 3m

FIGURE 4.7

PHOTOGRAPH FROM LLLTV MONITOR OVERCAST, ALTITUDE OF 5m, 200 ml OIL IMPACT

FIGURE 4.8

PHOTOGRAPH FROM LLLTV MONITOR AS ABOVE, 2 SECONDS AFTER IMPACT

FIGURE 4.9

PHOTOGRAPH FROM LLLTV MONITOR AS ABOVE, 25 SECONDS AFTER IMPACT

FIGURE 4.10

HASSELBLAD PHOTOGRAPH (UV FILTERED) BROKEN CLOUD COVER, ALTITUDE OF 20 m, ARROW INDICATES LOCATION OF OIL SAMPLE

FIGURE 4.11

PHOTOGRAPH FROM LLLTV MONITOR--CONDITIONS AS ABOVE

Broken sky conditions (6 to 9/10th cloud) existed at the time of the imagery. The visibility was unrestricted and the wind was from the NW at 3.1 m/s.

The photos show an area of extensive oil to the right of the boom. Some oil was escaping underneath the boom and was carried by the wind towards the left side of the photos. Both photographs were taken just after the Belore oil thickness sample was removed from the water surface. As indicated on the photos, a dark area of clean water was due to removal of the oil by the sampler. The thickness of the oil slick in these photos was 0.16 µm.

For slicks of this thickness, it appears that the volume reflected radiation component is not severely absorbed by the oil slick. As a result, the total radiance (surface reflected plus volume reflected) is at a maximum and provides maximum contrast. For thinner oil films, the oil present is not sufficient to produce a large surface reflected radiation component. For thicker films, the oil-water contrast is reduced due to absorption of the volume reflected component. Laboratory studies (Horstein, 1972; Fingas et al., 1979; Horvath et al., 1970) have shown that surface reflection dominates when slick thickness is in the range of 0.05 to 1.0 µm. Absorption of the volume reflected component will have a noticeable effect for thicknesses greater than 1 to 2 µm, depending on the light extinction properties of the oil present in the water surface.

Oil sampling to the right of the boom in Figures 4.10 and 4.11 was undertaken immediately before the pictures were taken. Slick thickness was 1.2 µm. A noticeable reduction in total radiance is evident at this thickness.

The operational characteristics of the LLLTV under large wave conditions could not be quantified since the highest waves experienced during the tests within the boomed area were only 0.3 metres. The small waves were the result of the dampening effect of the boom. Breaking waves only occurred at the shoreline.

It is difficult to compare waves caused by shoaling with breaking waves in the open ocean due to their different water motion characteristics. The motion of water near the shoreline was such that no oil or very little oil was observed within the wave breaker zone. With breaking waves offshore, the wave front will tend to thin the slick and transport it while the breaking action of the wave will agitate the slick dispersing some oil into the water column. This will tend to make the surface slick very difficult to detect with an LLLTV. It is difficult to draw any reasonable conclusions from this program that would be relevant to assessing the performance of the LLLTV under breaking wave conditionsoffshore. Neville et al. (1979) stated that ambiguous imagery was obtained with the LLLTV during high sea states when foam was indistinguishable from oil. The LLLTV was, however, able to distinguish between oil slicks and slicks of other origins such as wind slicks, boat wakes, internal waves, or freshwater lenses on seawater.

During this program, difficulties were experienced in differentiating oil from floating slush or chunks of ice. Figures 4.12 to 4.14 are a series of photographs taken at 1003 AST on February 22. Figure 4.12 is a UV filtered photograph, 4.13 is a true colour photograph and Figure 4.14 is a photograph taken from the LLLTV. Broken ice was present to the left of the boom, clear water was present at the upper right hand corner of the photos, and oil was present in the lower right area of the images. Note that the oil is indistinguishable from the ice on the LLLTV imagery and the UV filtered photograph. The colour photograph easily distinguishes the oil from the ice due to colour differences.

The LLLTV was also tested for its capabilities under reduced illumination levels. Figure 4.15 is a photograph taken by the LLLTV at 1752 AST February 22. The integrated incoming illumination at the time of the imagery was 15 Lux. This is the approximate lower illumination limit under which the LLLTV could differentiate between oil and water. Although the camera is designed to operate at a much lower light level, glitter severely degrades the picture quality. Glitter resulted primarily from a streetlamp

FIGURE 4.12

HASSELBLAD PHOTOGRAPH (UV FILTERED)-- ICE TO THE LEFT OF THE BOOM, OIL TO THE RIGHT, OPEN WATER IN THE UPPER RIGHTHAND CORNER OF IMAGE

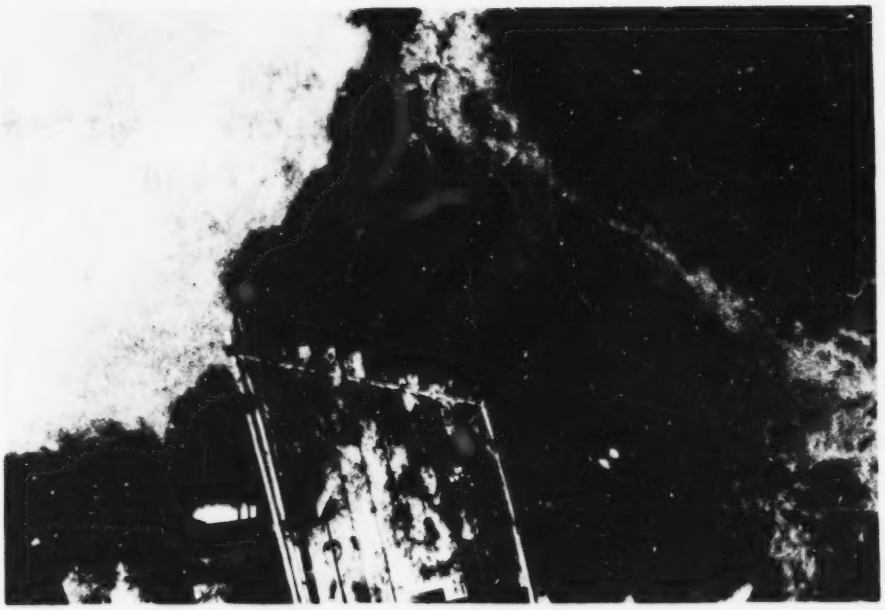


FIGURE 4.13

35mm PHOTOGRAPH (UNFILTERED) SAME CONDITIONS AS ABOVE

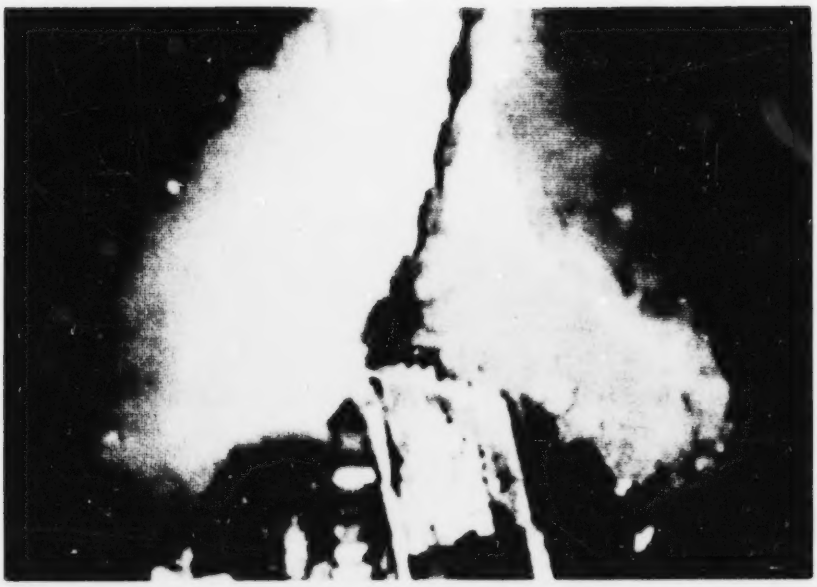


FIGURE 4.14
PHOTOGRAPH FROM LLLTV MONITOR
SAME CONDITIONS AS IN
FIGURES 4.12 AND 4.13

FIGURE 4.15

PHOTOGRAPH FROM LLLTV MONITOR--15 LUX ILLUMINATION

SIGNIFICANT FEATURES SHOWN IN PHOTOGRAPH ABOVE

located approximately 15 m from the shoreline. Other sources included the numerous lights from the refinery, and the lights from the City of Halifax located 2 km across the harbour. No attempt was made to reduce the sources of glitter since it is anticipated that any installation on an offshore platform would experience similar lighting conditions during darkness.

Although the detection limits of the LLLTV were severely compromised by glitter provided by artificial sources under low illumination conditions, the oil-water detection capabilities of the sensor at dusk and dawn were much better.

4.2.2 Parameters Affecting the Sensor Operation

The LLLTV operated without serious malfunctions throughout the study period. The sensor did not appear to be adversely affected by either cold or wet weather. The electrical and video cables were easy to install and connectors proved reliable over the course of the program.

The large field of view of the camera proved to be a great asset because an adequate frame of reference was available to discriminate between oil and water. This is essential with the LLLTV since oil is detected by determining a relative contrast between an oil slick and the water surface, not by absolute differences between the two.

The only problem experienced with the LLLTV system was the auto-iris feature. This proved troublesome whenever bright objects such as glitter or snow were present in the field of view and the lens was stopped down to reduce the incoming radiation. The auto-iris capability is, however, essential for long term remote operation in order to prevent damage to the detection unit.

4.3 PYRO-ELECTRIC VIDICON

The pyro-electric vidicon operates in the far infrared spectral region. The results of the evaluation suggest that it has limited application for remote sensing of oil slicks. It operates in the same spectral region as the Barr and Stroud IR imager tested in this evaluation (see Section 4.4.) and can detect similar gross features, but the sensitivity is much lower.

4.3.1 Factors Affecting Oil Detection

There were only a limited number of occasions during the evaluation when an oil slick could be positively identified with the pyro-electric vidicon. On these occasions, the operating height was 5 metres or less above the water surface and considerable movement was present within the field of view. During these conditions, when there was sufficient oil for the sensor to detect, the oil always appeared dark. Movement within the field of view was necessary since the sensor was operated without the chopper. With the chopper installed, movement in the scene is not required but the sensitivity of the system is considerably reduced. Oil was never seen when the device was operated with the chopper.

Movement within the scene could be created by either moving the sensor or viewing a field where motion was present. Panning of the sensor either in a hand held mode, or swinging the platform with the sensor hard-mounted did not usually provide sufficient motion for oil to be detected. An additional problem with this method was that areal coverage of the sensor was always changing which made positive identification of a target slick very difficult. During most of the testing program, the required motion was provided by wave action within the enclosure. Wave heights of less than about 10 cm did not provide sufficient motion to allow oil detection.

The operating height above the water was severely limited, again, because of lack of motion. The higher the sensor was mounted, the less the

relative movement within the scene. An operating height of 5 m was found to be adequate but the optimal height was 3 metres. This low operating altitude severely restricts the areal coverage of the sensor and limits its usefulness for application offshore.

Figures 4.16 and 4.17 are photographs taken from the monitor of the pyro-electric vidicon during a controlled oil release. The first photo shows the container of oil just before impacting the water surface. The oil retaining boom is evident to the right of the photo. The vidicon could not detect the surface slick that radiated away from the point of impact. It could, however, detect the oil that remained around the point of impact. The second photograph, Figure 4.17 shows the heavy semi-buoyant oil as a dark area near the impact point. The oil appears dark due to its lower emissivity. At no time during the tests did the vidicon sensor detect oil when the apparent temperature due to radiation differences was higher than that of the underlying water.

It is anticipated that under a clear sky and with the presence of a thick slick of heavy oil, the pyro-electric vidicon might be effective in differentiating oil from the surrounding water as the result of solar heating of the oil. For detecting thin oil films under overcast or foggy conditions, the pyro-electric vidicon does not appear to be an effective sensor.

4.3.2 Parameters Affecting the Sensor Operation

Due to the small size of the sensor and the simple mode of operation, the sensor was very easy to mobilize and operate. Since no cooling system is required for the detector, this eliminates any auxiliary equipment and the need for coolant refilling at fixed intervals. The sensor head does, however, require an environmental housing to keep it warm and dry.

FIGURE 4.16

PHOTOGRAPH FROM PYRO-ELECTRIC VIDICON MONITOR IMMEDIATELY PRIOR TO OIL IMPACT-- OIL BOOM TO RIGHT

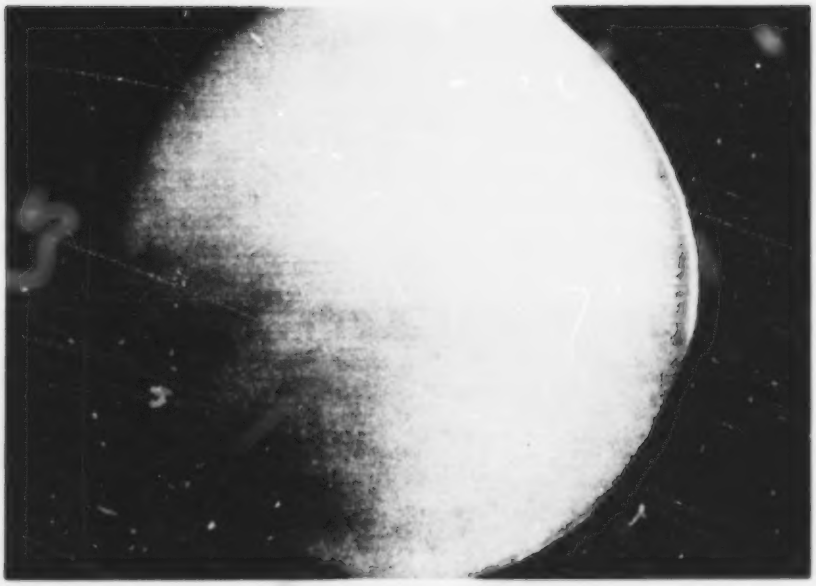
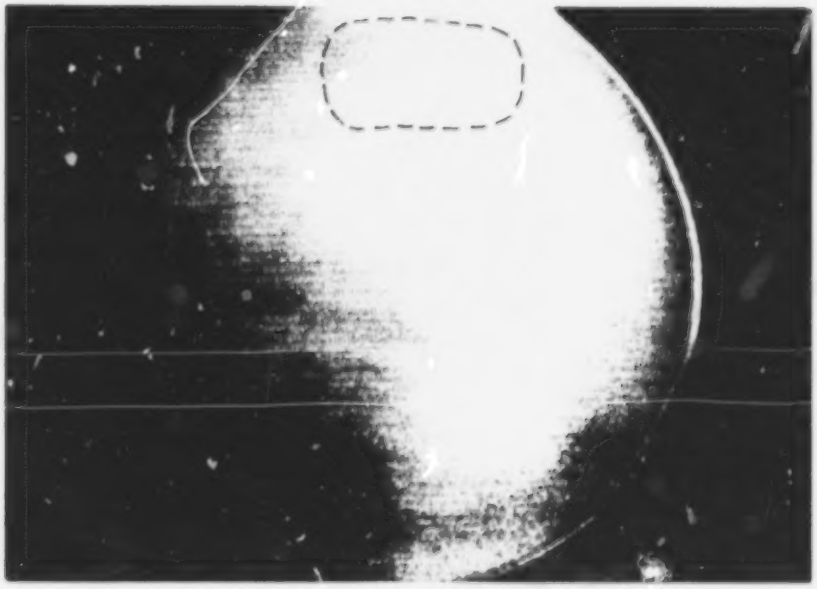


FIGURE 4.17

PHOTOGRAPH FROM PYRO-ELECTRIC VIDICON MONITOR AFTER OIL IMPACT



OILED AREA IN PHOTOGRAPH ABOVE

4.4 INFRARED IMAGER

The Barr and Stroud thermal IR imager was able to detect oil on the water surface during the evaluation program, but the results obtained were difficult to interpret. The conditions under which the sensor was able to detect oil are difficult to summarize because a number of factors combined to produce targets that appeared similar to oil.

Its erratic behavior due to coolant problems in the detector limited the amount of time available for evaluation of the device.

4.4.1 Factors Affecting Oil Detection

As expected, during overcast conditions or darkness, the emissivity differences between the oil and water were usually large enough to provide sufficient contrast to permit detection of the slick by the IR imager. Even though the water and oil were at essentially the same temperature, the oil appeared cooler in the image, apparently due to its lower emissivity.

During most daytime conditions, the slick inside the boom appeared as a lighter tone than the water surface outside which indicated that the oil had a higher apparent temperature. Using a standard field thermometer, a difference in temperature between the two areas could not be detected. The higher apparent temperature of the oil slick could have been due to two factors. The oil slick may have been heated by the incoming solar radiation or it could have been retarding evaporation from the water surface. Since the oil slick was composed of mainly weathered crude, evaporation from the slick was minimal.

Suspended oil globules in the water such as those shown in Figure 4.18 appeared dark. These particles did not experience significant solar heating since most of their mass was below the water surface. They retained the temperature of the water and due to their lower emissivity, always had an apparent temperature below that of the surrounding water.

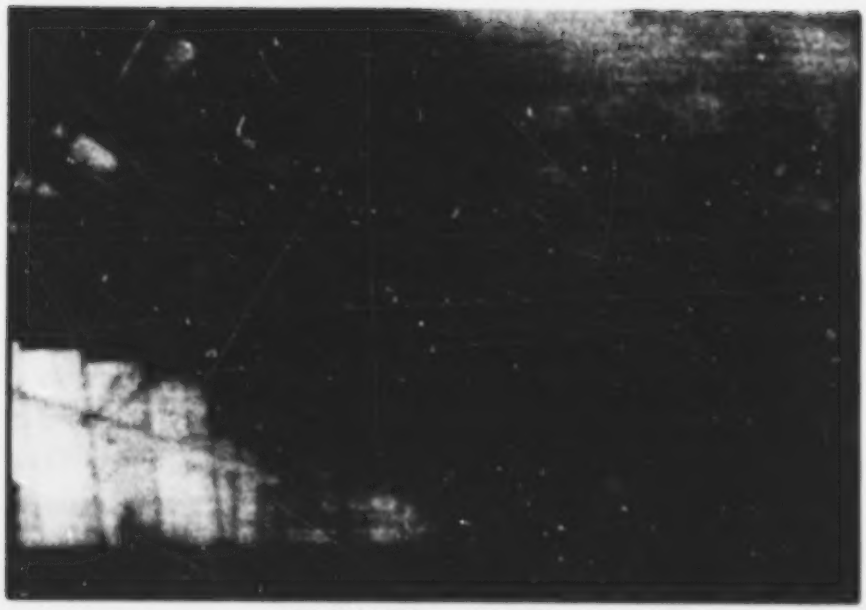


FIGURE 4.18

PHOTOGRAPH FROM INFRARED IMAGER MONITOR--
OIL GLOBULES IN CENTRE OF IMAGE

Figure 4.18 shows a photograph taken from the IR Monitor at the same time as the imagery shown in Figures 4.12, 4.13 and 4.14. The dark areas in Figure 4.18 are oil particles trapped between the shore and the oil boom by the combined effect of wind and wave action. To confirm that the detector was actually "seeing" oil, 200 ml of oil was released in the impounded area. The areal extent of the presumed oil globules increased in approximate proportion to the additional amount of oil released.

The difficulty in interpreting IR imagery is that a combination of other features can produce a target that appears similar to oil. For example, the ice present to the left of the boom in Figure 4.18 appeared very cold. It is possible that a certain proportion of the area thought to be oil did in fact contain ice crystals that appeared similar to oil. Floating debris such as wood chips and other objects were often observed in the boomed area during the evaluation. They usually appeared cold, but could usually be differentiated from oil by their physical shape. Other false targets included air bubbles caused by surface turbulence and snowflakes melting on contact with the water surface.

In most circumstances during the evaluation, the suspended oil particles appeared cold, the water warm and the oil slick hot in the IR images.

There were, however, many instances during the program when oil was present but not detected by the sensor. Figure 4.19 shows a 200 ml container of oil just before it made contact with the water surface. To the right of the photograph is a portion of the oil retaining boom that was heated by insolation. For reference, this imagery was taken at the same time as Figure 4.7 and Figure 4.17. Although the oil in the container appeared hot in the IR image, within a fraction of a second of the oil contacting the water surface it could not be detected. The conclusion that can be drawn from this is that the difference in apparent temperature between the oil and water was insufficient to produce a contrast large enough for the sensor to detect the oil. This was a result of hot oil

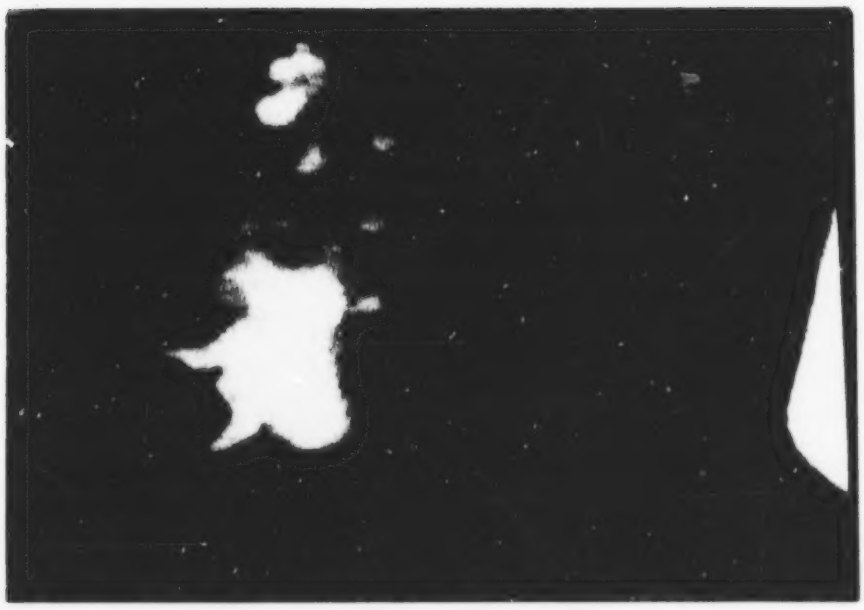


FIGURE 4.19

PHOTOGRAPH FROM INFRARED IMAGER MONITOR-- IMMEDIATELY PRIOR TO IMPACT OF OIL ON WATER, OIL BOOM ON RIGHT

forming a thin slick that spread out quickly, the temperature of which rapidly equilibrated to that of the water. Due to an insufficient difference in oil-water emissivities, and/or the limited thickness of the oil film, the slick appeared to vanish.

Figure 4.20 was taken 1/15 of a second after the moment of oil impact and shows the hot surface slick which spread out rapidly and then disappeared. Figure 4.21 was taken 10 seconds after release and shows the semi-buoyant oil particles with a low apparent temperature near the top of the photograph.

Evaporation leading to cooling of the slick surface was not considered a factor in this situation because most of the volatile fractions would have been lost in the separators. There was, however, one example where evaporative cooling was an apparent factor in allowing the detection of a surface slick. At the time, scattered clouds were present and winds were from the north at 5.1 m/s. Figure 4.22 shows the IR imagery a few seconds after 200 ml of gasoline were released onto the water surface. Due to the limited field of view of the imager, only about half of the slick area is shown. The characteristics of the slick did not dramatically change during the 30 seconds it was in the field of view of the sensor. The IR imagery was taken at the same time as the LLLTV imagery shown in Figure 4.23. The gasoline film could not be differentiated from the water surface in the LLLTV imagery. It appears that gasoline must have reflectance properties similar to those of water.

Although the IR imager was not affected by glitter in this example, there were a number of instances when oil could not be detected due to specular reflection. Global radiance levels in the far IR are low and glitter would not be expected to cause significant interference. Figure 4.24, however, shows an example of considerable glitter. Although some definition of surface characteristics is possible in this image, the quality is considerably reduced.

FIGURE 4.20
PHOTOGRAPH FROM INFRARED IMAGER MONITOR IMMEDIATELY AFTER OIL IMPACT

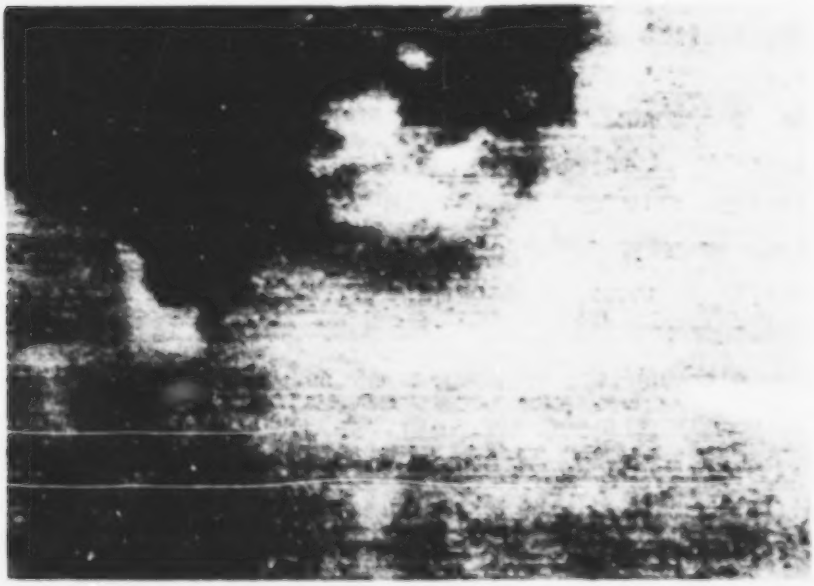


FIGURE 4.21
PHOTOGRAPH FROM INFRARED IMAGER MONITOR TEN SECONDS AFTER OIL IMPACT

FIGURE 4.22
PHOTOGRAPH FROM INFRARED IMAGER MONITOR SEVERAL SECONDS AFTER GASOLINE RELEASE

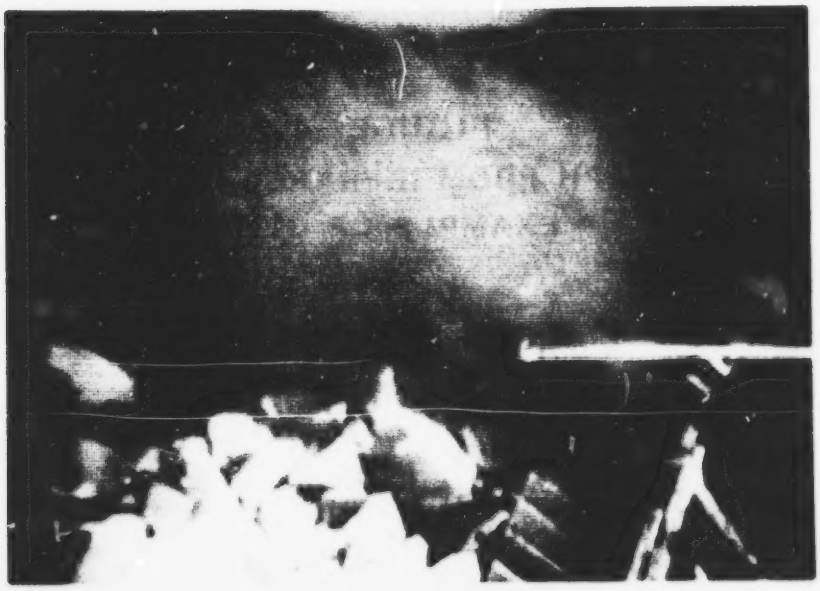


FIGURE 4.23
PHOTOGRAPH FROM LLLTV MONITOR--SAME CONDITIONS AS ABOVE

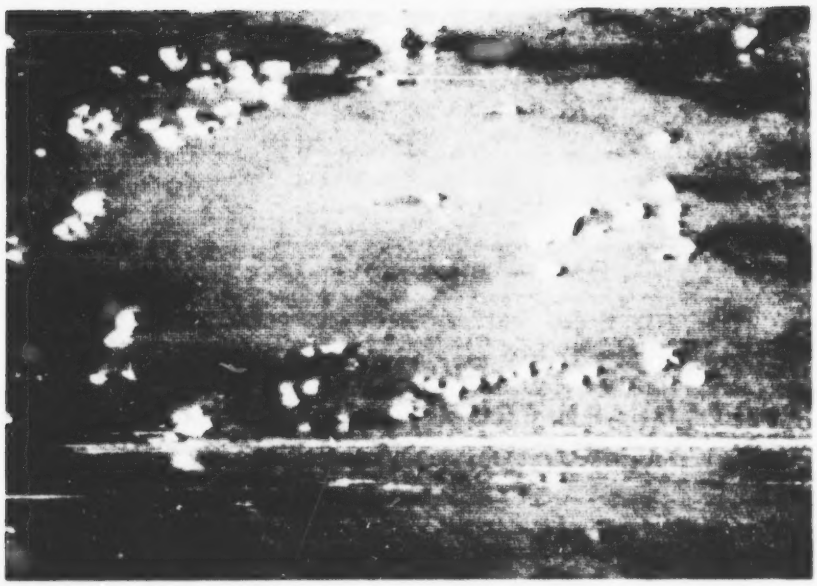


FIGURE 4.24
PHOTOGRAPH FROM INFRARED IMAGER MONITOR--
EXAMPLE OF GLITTER

Results from operation at night with the IR imager were encouraging when sufficient oil was present and wave conditions were not severe. High waves generally produced too much turbulence to allow positive identification of oil.

Oil films at night were always seen as hot areas despite the lack of solar heating. This may have been due in part to a thermal barrier between the cold air and warmer water. The initially higher temperature of the oil from the effluent compared to that of the seawater may have contributed to this as well. Images at dawn and dusk did not appear significantly different from those taken during operations at night.

Figure 4.25 shows IR imagery taken just after dusk at 1652 on February 22. The sensor height above the water was 10 metres. It was positioned to look vertically downwards. An 8.2 m/s wind blowing from the west created 0.3 metre waves in the boomed area. An example of LLLTV imagery, taken at the same time, is shown in Figure 4.15. The IR image shows a dark area to the left which is the water surface and a light area to the right which is the oil slick. Another example of similar imagery is shown in Figure 4.26. This was taken under illumination conditions of 2.5 Lux at 1720 on February 22. The oil slick inside the boomed area is clearly evident as a lighter area in the image.

4.4.2 Parameters Affecting the Sensor Operation

The IR imager proved to be the most labour intensive of the sensors evaluated in this program because of the air compressor used to fill the high pressure air bottle needed for detector cooling. The air filtration system on the compressor was inoperative and unfiltered air was unknowingly used during the majority of the field program. Contaminants in the air resulted in the premature shutdown of the electronics, but only when the camera was operated in the vertical position. This problem required constant attention and limited data retrieval for the sensor to about 50%

FIGURE 4.25

PHOTOGRAPH FROM INFRARED IMAGER MONITOR--
ALTITUDE OF 10m, JUST AFTER DUSK, OIL SLICK TO RIGHT

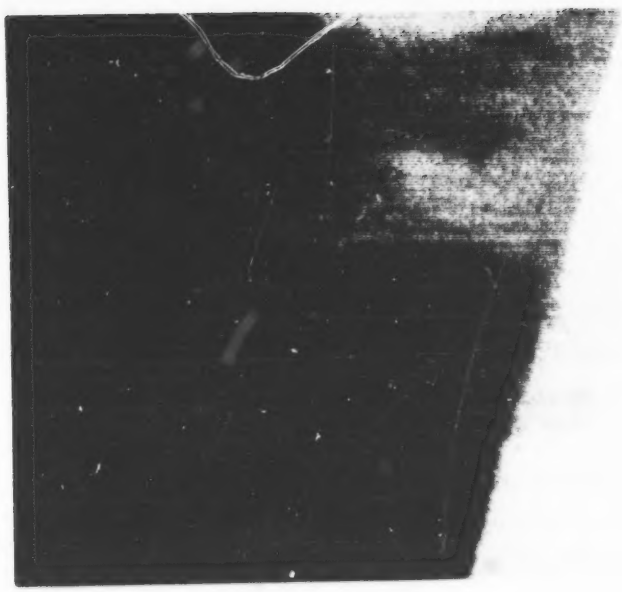


FIGURE 4.26

**PHOTOGRAPH FROM INFRARED IMAGER MONITOR--
ILLUMINATION OF 2.5 LUX, OIL TO RIGHT OF BOOM**

of the total program. The bottle supplied with the unit held sufficient air for approximately four hours of sensor operation.

Although the IR imager was one of the larger sensors used in the program, the unit is well-constructed, robust and does not require an environmental housing for normal outdoor operation. However, a better video output connector should be designed and installed. Shorting did occur at this connection during wet weather. The relatively narrow field of view does limit its capability for detecting oil when operating at low altitudes.

4.5 OILSPILLS

Unlike the previous sensors which are designed to detect the actual presence of oil on the water surface, the Oilspills is designed to detect the presence of vapours emitted by a slick by measuring the thermal absorption resulting from the presence of hydrocarbons in the atmosphere. The response of the detector is dependent upon the magnitude of the thermal contrast between the vapours and the source. Precise measurements of the surface temperatures and air temperature in the sensor's path were not made. Therefore, a quantitative interpretation of this parameter was not possible. However, the difference between water temperature measurements and shore-based air temperature measurements indicated that there should have been a sufficient temperature difference for hydrocarbon vapours to be detected.

Since in all but one case, the Oilspills failed to detect the presence of oil, it is difficult to draw conclusions as to the capabilities of this sensor for the desired application. From the technical summary presented in Part 3, however, it appears that the reason for the poor results was insufficient evaporation from the slick rather than a small thermal contrast.

4.5.1 Factors Affecting Oil Detection

For the Oilspills to perform optimally, the thermal contrast between the vapours and the source should be large, wind speeds should be minimal, and the evaporative flux should be sufficient to produce a vapour cloud. Hydrocarbon vapour contamination from other sources such as exhausts and industrial activities should also be minimal.

Based on these criteria, the conditions under which the Oilspills was tested were clearly far from ideal for the instrument. Water temperatures varied from 0° to +2°C while the mean daily air temperatures were between -13.8° and +2°C. Maximum daily temperatures varied between -11.5° to +4.5°C and minimum temperatures were between -16.0° and -0.2°C.

The thermal contrast between surface water temperature and air temperature was as high as 18°C during the program, but for most of the operation period the difference was between 0° to 10°C. Mean wind speed over the duration of the tests was 17.6 km/hr. Hydrocarbon vapour contamination as a result of the location of the test site at the refinery might have been an interfering factor. However, it was not evident in any of the results obtained.

The oil discharged from the API separators was not highly volatile. As indicated by the chromatograms shown in Part 3, the discharged hydrocarbons were chiefly weathered crudes that had already lost most of the volatile fractions.

It is impossible to deduce the exact reasons for the poor performance of the sensor; however, some insight into the sensor performance can be gained by studying the conditions under which the sensor did perform as expected.

Figure 4.27 shows the situation in which the Oilspills performed as expected. It occurred on February 15 when the platform was moved from outside the boom to the boomed area where a substantial slick was present. The figure contains plots from both the radiance channel and the gas channel of the detector. At the time, the sky was overcast, wind velocity was 6.1 m/s and the air temperature was +2°C. Wave heights were estimated to be 7.5 cm in the boomed area. The calm weather conditions ensured that the boom was retaining all the oil and none was escaping into the surrounding water. This ensured that maximum contrast conditions existed.

As explained in Section 2.1.5, the Oilspills detects the hydrocarbon vapour plume when the electronic balance between the sample cell and gas cell signal is upset. Ideally, the sensor would be used over a uniform surface where no radiance changes would occur except as the result of hydrocarbon vapours in the sensor field of view. This is, however, not generally the situation in the field. The sensor has difficulty differentiating radiance changes due to hydrocarbon vapour from rapidly changing background radiance signals. Figure 4.28 shows output from the Oilspills sensor during large changes in radiance. The asterisks indicate when background radiance changes resulted in an immediate and incorrect response by the gas channel, producing a false signal.

From the tests conducted, it is impossible to make any final judgement on the general capabilities of the Oilspills sensor. It appears to be insensitive to the types of conditions encountered in the present program, i.e. thin slicks, weathered oil, and small temperature differences.

4.5.2 Parameters Affecting the Sensor Operation

As with the IR imager, operation of Oilspills was found to be labour intensive. This was due in part to the fact that the sensor was a prototype. The sensor is designed to produce analog output overlayed on top of the image from the video-camera. Only the gas and radiance signals available in either analog or digital format were available during the

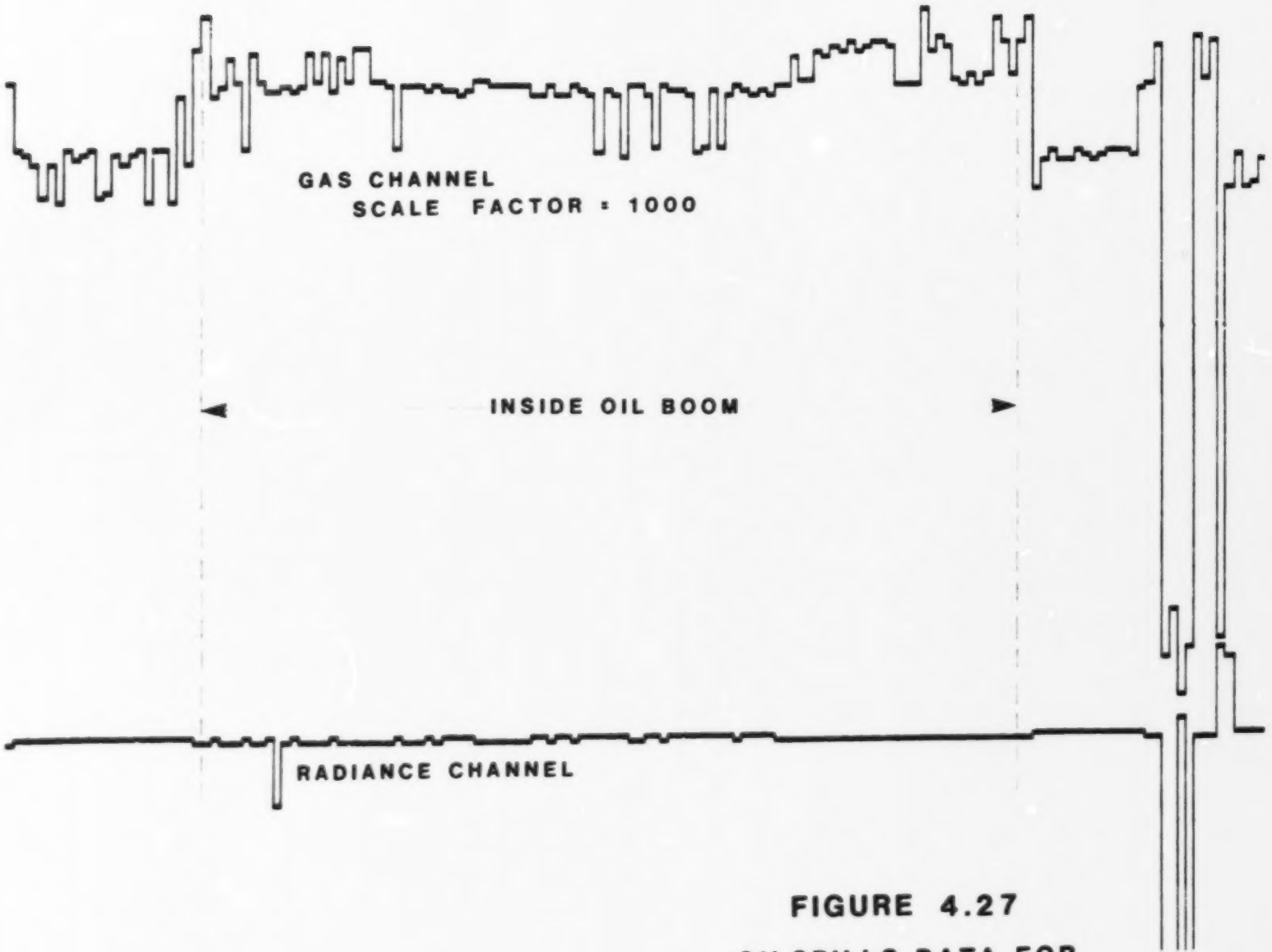
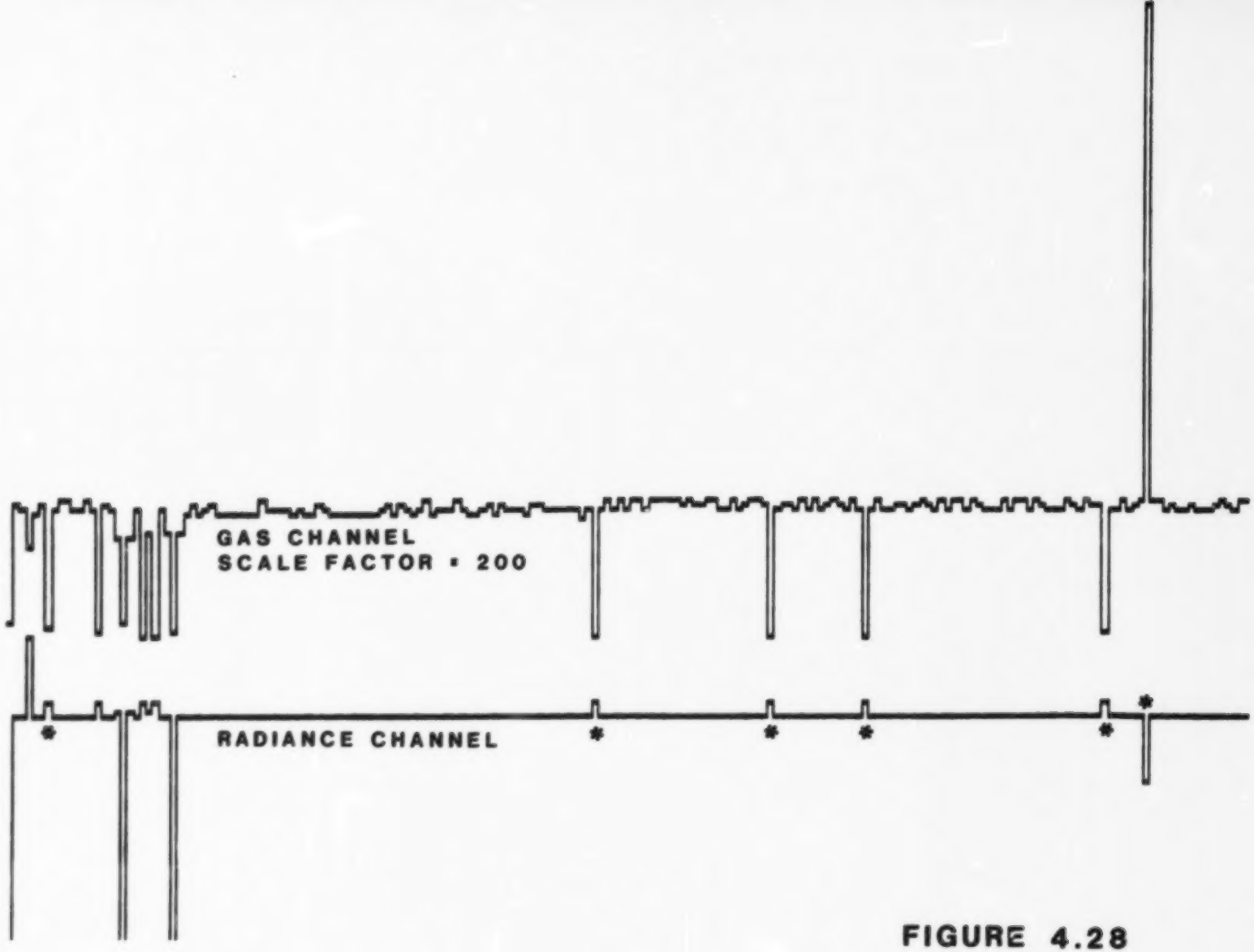


FIGURE 4.27

OILSPILLS DATA FOR
15 FEBRUARY 1985
DATA POINTS 1-160



*RAPID CHANGES IN RADIANCE

FIGURE 4.28

OILSPILLS DATA FOR
15 FEBRUARY 1985
DATA POINTS 1-200

program. Chart recorders were used for a short period to record the data but they proved ineffective due to the large variations in signals and difficulty in the interpretation of such a large amount of information. Storage of information using a micro-computer was also used, but real time interpretation of the data, using this method, was not possible. Special computer programs would have been required to receive, store and plot the information in real time.

Data acquisition during the majority of the study involved the storage of the gas and radiance signals on the audio track of the VCR which later could be stripped off and analyzed using a micro-computer. A software error in the program that wrote the information to tape caused some information to be overwritten and as a result, less than 40% of the data were recovered. Problems with extraneous noise on the tape were also experienced, and were probably the result of shorting between the contacts of the amphenol connectors during wet weather.

Even if further testing proves that the Oilspills sensor has the capability for detecting oil slicks, the sensor has a number of requirements that may be difficult to maintain in an offshore situation. The sensor requires liquid nitrogen that has to be replenished every four hours. Although relatively small volumes are required, this could prove to be very inconvenient particularly if the sensor is mounted under the platform to allow it to scan a wider area. Mounting on an offshore structure would also require the design of a waterproof housing, and the thermoelectric cooling system used to regulate the temperature of the chopper and gas correlation cell would also require modification because forced air is used at the present time.

PART 5

SUMMARY AND RECOMMENDATIONS

5.0 SUMMARY AND RECOMMENDATIONS

5.1 GENERAL

This section of the report is a summary of the findings for each unit evaluated during the program and compares their capabilities in relation to a series of standard parameters applicable to offshore oil spill monitoring applications. This is followed by a series of recommendations for further work to clarify the findings of the present evaluation and to determine the operational limitations of units that did not perform up to expected standards.

5.2 SENSOR SUMMARY

A summary of the oil detection capabilities and operational experience with each of the units is presented below.

5.2.1 Photographic Cameras

The UV filtered and regular cameras used in the evaluation program performed well and yielded good results when suitable conditions prevailed. However, both units require substantial illumination to produce good images and therefore cannot be used in twilight or dark conditions. UV photography has better oil-water differentiation capabilities than normal photographs but it is impossible to differentiate oil from broken ice present in the field of view. The cameras are limited in their capability because they cannot provide a continuous record that is available for interrogation in real time. This, combined with limited film capacities, would restrict the suitability of photographic units as the primary sensor for offshore monitoring. However, they would be highly suitable support units to a primary unit.

5.2.2 LLLTV

The UV filter-equipped LLLTV had excellent oil-water discrimination capabilities when conditions were suitable. Optimal operating conditions were encountered when the sky was overcast and the water was relatively calm. The LLLTV exhibited degradation in image quality when any bright point source or sources of light such as snow or glitter from incident sunlight or artificial lights was present. This problem would compromise the capability of this unit to operate on offshore platforms at night when glitter from operating lights on the sea surface could be severe.

The LLLTV, however, proved very reliable, easy to operate, and had a wide field of view, making it an almost ideal candidate for the type of applications proposed for offshore platforms.

5.2.3 Pyro-Electric Vidicon

This unit, which operates in the far IR, proved to be operationally reliable, but the detection capabilities of the unit were minimal. It was unable to discriminate between an oil slick and the water surface, although it did have some capability for detecting oil globules. In addition, the requirement for relative horizontal motion in order to distinguish between oil and water suggests that it would not be a reliable unit in remote situations where the recorded data could not be verified independently.

5.2.4 Infrared Imager

It is difficult to reach definite conclusions about the capabilities of the Barr and Stroud IR Imager because of the operational difficulties which limited data recovery during the program, and the difficulty in interpreting the image being received relative to the other units tested. It is evident that considerably more interpretation experience is required with this unit than the others tested. Snow, air bubbles and ice fragments all affect the ability of observers to properly discriminate between oil

and water on the sea surface. The IR imager, however, was the only unit capable of consistently detecting oil at night. This sensor system is not as compact or convenient to use as the other sensor packages. The electronics are relatively complex and an air compressor capable of supplying ultra-dry, contaminant free air is essential. The controls at present are not appropriate for offshore applications, although these could be redesigned if the basic concept was deemed to be appropriate.

The field of view of the sensor is very confined for the distances from the source at which the sensor would be expected to operate (i.e., $\leq$50 m). This could be corrected by changing the lens on the detector, but at the expense of spatial resolution at the source. The effect of this change cannot be anticipated based on the present program results.

5.2.5 Oilspills

Few conclusions can be drawn about the capabilities of the Oilspills sensor. The unit generally could not discriminate between oil slicks and the water surface under the conditions tested. This was due in large part to the relatively low evaporation rates from the oil present in the boomed area. This limitation would be expected to compromise its ability to detect small volumes of low volatility oils present on the sea surface.

The unit was a prototype and it was not possible to obtain real time data during the program. This limited the ability of the field team to manipulate conditions in an attempt to define the discrimination limits of the sensor.

5.3 SENSOR COMPARISON

A comparison of sensor capabilities as demonstrated during the field program is contained in Table 5.1. The field program was designed to provide conditions at least partially representative of those which would be expected at an offshore platform. Therefore, the evaluation contained

TABLE 5.1

SUMMARY OF OPERATIONAL ABILITY OF SENSORS
BASED ON EVALUATION PROGRAM RESULTS

Description of Ability	UV Filtered Photographs	Pyro-Electric Vidicon	LLLTV	Infrared Imager	Oilspills
Real Time Oil Surveillance	0	0	2	2	0
Determination of Oil Thickness	0	0	0	0	0
Determination of Oil Specificity	0	0	0	1	0
Oil Type Discrimination					
Heavy	1	1	1	2	0
Crude	2	0	2	2	0
Light Refined	1	0	1	2	0
Performance Under Representative Lighting Conditions					
Day Clear	1	0	1	2	0
Day Overcast	2	0	2	2	0
Twilight	0	0	1	1	0
Night	0	0	0	2	0
Performance Under Various Atmospheric Conditions					
Clear	2	0	2	2	0
Precipitation	2	0	2	2	0
Cloud	2	0	2	2	0
Fog	2	0	2	2	0
Performance Under Various Sea States					
Calm	2	0	2	2	1
Moderate	1	1	1	2	0
Optimal Orientation	away from sun	vertical	away from sun	vertical	vertical
Optimal Height	>10 m	<5 m	>10 m	>10 m	>10 m
Ease of Interpretation of Image	2	0	2	0	0
Ease of Operation	1	1	2	0	0
Reliability	1	1	2	0	0

Evaluation Code: 0 - poor 1 - fair 2 - good

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Crude	2	0	2	2	0
Light Refined	1	0	1	2	0
Performance Under Representative Lighting Conditions					
Day Clear	1	0	1	2	0
Day Overcast	2	0	2	2	0
Twilight	0	0	1	1	0
Night	0	0	0	2	0
Performance Under Various Atmospheric Conditions					
Clear	2	0	2	2	0
Precipitation	2	0	2	2	0
Cloud	2	0	2	2	0
Fog	2	0	2	2	0
Performance Under Various Sea States					
Calm	2	0	2	2	1
Moderate	1	1	1	2	0
Optimal Orientation	away from sun	vertical	away from sun	vertical	vertical
Optimal Height	>10 m	<5 m	>10 m	>10 m	>10 m
Ease of Interpretation of Image	2	0	2	0	0
Ease of Operation	1	1	2	0	0
Reliability	1	1	2	0	0

Evaluation Code: 0 - poor 1 - fair 2 - good

in Table 5.1 is based soley on the sensor performance during the field program. Credit was not given for factors such as theory of operation or potential detection capabilities when operating under different or optimal conditions.

The sensors were judged on a scale of zero to two to indicate their usefulness or applicability for the proposed task. Under this system, a zero indicates that the sensor was unable to perform the task or performed the task poorly. Categories included those pertaining to the detection capabilities of the sensors as well as operational considerations.

It was apparent that the UV filtered photography shows no capability for real time surveillance, oil thickness measurement, or determination of oil type. Detection is best with crude oil slicks. Light refined products are too transparent, while weathered crudes often form into tar balls that may float slightly under the surface of the water. Optimal illumination conditions occur under slightly overcast skies. Operation with clear skies is possible as long as glitter from the sun is not spatially continuous. Operation is possible under all but the most adverse meteorological conditions. Oil detection capabilities are severely restricted when high wave conditions occur and during darkness. The photography is easy to interpret. Cameras, being mechanical devices, have only limited reliability and require regular attention to reload film. The optimal operating height depends on the field of view of the camera and the wave conditions at the point of installation.

The results from the Pyro-Electric Vidicon are not complete enough for a thorough assessment of its operational capabilities. In the few instances when oil was positively detected, the sensor was operated at a height above the water of 5 metres or less, there was a fair amount of wave action, and the oil that was detected was semi-buoyant globules. The sensor was rated as having only fair reliability since at one point during the test, the sensor failed to operate properly due to low air temperature.

The LLLTV has good capabilities for oil surveillance due to the simplicity of operation and the lack of complicated support equipment. It operates best when used to detect crude oil slicks. Light refined products are too transparent and slicks composed of weathered crudes often break up to form oil globules which may or may not be emulsified. The LLLTV has the same operational constraints as the UV photographic cameras with the exception that it can operate under much lower illumination conditions. The LLLTV is easy to operate and very reliable, and the output is easy to interpret.

The Barr and Stroud IR imager has the capabilities required for oil surveillance although the results suggest that it could not be used as a "stand alone" system because of the high frequency of false targets recorded in the program. The imager has no capability for determining slick thickness or oil type. The ease of oil detection is a function of environmental conditions and oil type. Twilight conditions combined with high waves produce the least favourable conditions for oil observation. The output of the IR imager was difficult to interpret, the operation of the sensor was time consuming and the system was unreliable. The latter two observations were mainly the result of the contaminated air supply used in the sensor cooling system.

Operation of the Oilspills sensor produced virtually no useable data. On the one occasion when the sensor did perform as expected, minimal wind speeds were recorded.

5.4 RECOMMENDATIONS

The results of the present field evaluation program revealed that two of the passive sensors, the LLLTV and the IR imager, demonstrated a potential for detecting oil slicks on the water surface. The other units, the pyro-electric vidicon and the Oilspills, had very limited capabilities. These two units could not discriminate between oil and water under most of the environmental and oil spill conditions encountered during the test

program. A number of recommendations can be made based on the program results and the operating experience gained with the sensors during this program. These are listed in point form below.

1. The sensitivity of the pyro-electric vidicon is insufficient to discriminate between oil slicks and the water surface under most conditions encountered during the present program. Further testing of this unit is not recommended.

2. The Oilspills unit should be tested under conditions when adequate thermal contrast exists, and the cooperative flux of the signal source is sufficient to elicit a response. This will assist in determining how discretely the unit can differentiate between an oil slick and the sea surface. However, before this is undertaken, a field tested fully operational prototype should be available and an evaluation of the probability of slicks from offshore spills meeting the minimum condition detection requirements of the unit should be undertaken.

3. Photographic units of the type used in the present program should be included in any future evaluation because they can provide high resolution and good definition of the slick. They provide a good yardstick for comparing the performance of the other units present.

4. A situation that could not be resolved in the present evaluation was the effect of wave height on the discrimination capabilities of the LLLTV and the IR imager. In offshore situations, high horizontal and vertical surface velocities could result in blurring of the images. The ability of these sensors to discriminate under large wave and marginal radiation conditions may be a major deficiency that should be investigated.

5. Definition of an adequate field of view is required because present interpretation depends on the ability to derive a visual contrast between the oil slick and the water surface. If an oil slick completely fills a field of view, in marginal radiation conditions, then the ability to determine the medium that is being viewed may be severely compromised. This is particularly true when a sensor may be interrogated only infrequently. The incorporation of a zoom lens with a wide angle capability may be a partial answer.

6. The Barr and Stroud infrared imager should be evaluated without the telescope attachment in order to provide a larger field of view. The objective would be to determine how the loss of spatial resolution compromises the slick discrimination capabilities of the unit.

7. The present program evaluated only passive sensors. Active sensors such as the Wright and Wright Oil Film Monitor, laser fluorosensors or microwave units that have been developed or are currently being developed should be evaluated. The active sensors may offer advantages because the radiation sources can be controlled and they potentially offer the ability to discriminate absolutely between the water surface and oil. This latter feature would be highly desirable because it would remove the need for on-site verification of the presence of oil on the water and the need to provide very extensive training for operating personnel in the interpretation of the images being received at a shore monitoring station.

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